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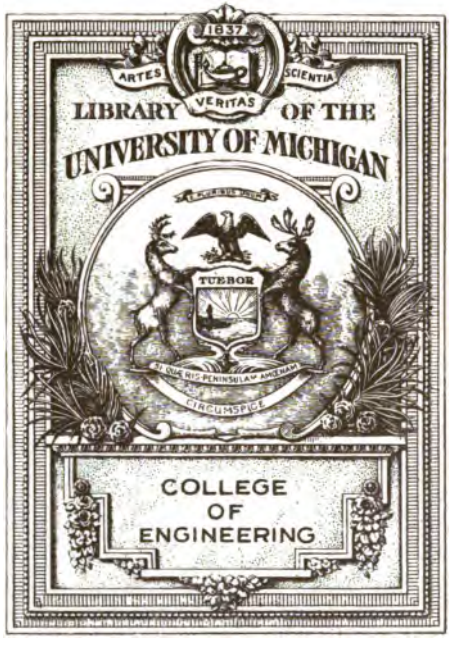
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INAUGURAL ADDRESS

BY THE PRESIDENT,

MR. JOSEPH NASMITH,

DELIVERED SATURDAY, 11TH JANUARY, 1896.

THE INVENTIVE EPOCH IN THE COTTON TRADE.

It is not an easy task to select a subject for an address of this character, but it is following a good precedent to deal with that side of engineering with which the writer is most familiar, especially as it will have some features of novelty to many members.

The origin of the textile art is lost in antiquity. The most ancient records which we have, whether graven on stone or inscribed on parchment, speak of the textile art as an established one. Linen, silk, and wool would appear to have been earliest known, especially the former, but the analysis of the mummy cloths of Egypt has shown that cotton was not unknown. The first historical reference of a distinct nature to that fibre is found in the writings of the first historian Herodotus, who speaks of it as in use in India. The opening up of the East by Alexander and the subsequent invasion of the South and West of Europe by the Moors brought cotton into great use. There is also evidence that this textile fibre, with the rest, was known on the Continent of America prior to its subjugation by European races.

It is not likely that all the possibilities of these natural fibres would be long overlooked, and although it is difficult to find any

record of a time when spinning and weaving did not exist, there must have been for long ages the most primitive forms of each. Spinning by the distaff and spindle, which was purely a manual operation, existed right down to the present century in spite of the development of the hand spinning wheel. Primitive looms exist and are in use at the present day in some parts of the world. If this were the proper time and place evidence could be given of the existence of a sort of mosaic of ancient and modern practice right up to our own era.

About the middle and close of that eighteenth century to which much attention has been directed by historians of all kinds, there began an inventive movement which has changed the face of the world. It has been well and truly said that Shakespeare was the product not of his own but of all ages. The development of national life, which had been struggling in the narrow bounds of custom and feudality for many years, found in the reign of Elizabeth an outlet for all its energy and many-sidedness, and attained a fulness and richness which is reflected in the Shakesperean verse. And so the great struggle which was in progress in Europe, the enormous increase in the possessions of this country, the growth of foreign commerce, all tended to lead up to an era of invention, when existing wants would be fully met and new ones created. It is not an exaggeration to say that it was as much because the time was ripe as because of the merits of the inventions that they came in such rich profusion and had so large an influence upon the course of manufacture.

Look for a moment at the state of England towards the end of the last century. Communication between various parts of the country was slow and uncertain; the population was largely agricultural, badly fed, and superabundant when compared with the means of livelihood. Here and there, as in Manchester, Birmingham, and Leeds, large aggregations of craftsmen and

tradesmen existed, and these drew into their walls workers from outside districts. The war which was running its course drained the country of its resources, but did not entirely cut off intercourse with foreign lands. How important English commerce had become is proven by the continued and repeated attempts, at a later date, of Napoleon to close Continental ports to our ships. In spite of these attempts the trade of the country flourished, and a demand grew which it was difficult to cope with by the means at hand. The conquest of India brought into our markets their fine textile goods and the raw material; the colonisation of America created a new market for British goods. So it happened that the times were ripe for the work of the inventive genius, but, as often occurs, the breaking of the ice was followed by an outflow of energy which in fifty years carried the nation further than it had moved in the three hundred preceding. Action and reaction followed each other in regular sequence until an almost purely agricultural community grew into one mostly engaged in manufacturing. The change was portentous, and shrewd observers speedily saw in it that revolution in the mode of life, thought, and action which has since come to pass.

It is not now intended to go into details of the whole sequence of inventions which may be said to have found their culmination in Roberts' mule, but to deal with those of which it may be said that they covered the whole field.

Up to quite recent times the work of drawing cotton or flax from the distaff, on which it was placed, was a purely manual operation. The spinster in doing so formed it roughly into a thread, and, by the rotation of the spinning wheel, either by hand or foot, twisted it into yarn. So dexterous did they become, that the operations went on nearly continuously, this being a great advance on the older form of spinning, in which the thread was formed by twisting the material by the fingers, and so rotating a suspended spindle to which it was attached.

After a certain length was spun it was wrapped on the spindle and a new piece begun. It is well to note at this point the two principal forms of wheels used. In one, which was more common in spinning wool and cotton, the yarn was spun by means of a horizontal spindle, driven by the wheel, and on which, after spinning, the yarn was wound in the form of a cop. The spinster during twisting held a certain length of the previously formed roving between her fingers and the spindle, and allowed the twist to be put in. She then gradually allowed her hand to approach the spindle so that the yarn was slowly wound on. In the other form a flyer was employed, which revolved round a bobbin placed loosely on the spindle, the rotation of the flyer twisting, and the weight of the bobbin retarding it sufficiently to enable it to wind on the yarn. Attention is specially called to those two forms, because they were the prototypes of the machines which were subsequently constructed. The rotation of the wheel and spindle could be made continuous by the addition of a treadle, which left the hands of the spinster free. Clearly, therefore, some contrivance which drew the cotton from the mass without the use of hands, was that which was needed to render the process substantially automatic. In this apparently simple step was found the germ of all that mighty growth which has since overspread the world. Out of it sprang not only a new method of spinning, but also a new social development, the full fruition of which is not yet accomplished.

The honour of making this step belongs to John Wyatt, of Birmingham, although his name does not appear on the patent specification. This was taken in the name of Lewis Paul, but there is no doubt that the real inventor was Wyatt. It is not necessary to go into the matter at length, because it is the importance of the step rather than who was the inventor which is in question. The patent was obtained in 1738, and the

specification contained the following words: "The Wooll, or Cotton being thus prepared, one end of the Mass, Rope, Thread, or Sliver, is put betwixt a pair of Rowlers, Cillinders, or Cones, or some such movements, which being twined round by their motion, draws in the raw mass of Wool or Cotton to be spun, in proportion to the velocity given to such Rowlers, Cillinders, or Cones; as the prepared mass passes regularly through or betwixt these Rowlers, Cillinders, or Cones, a succession of other Rowlers, Cylinders, or Cones moving proportionably faster than the first, draw the Rope, Thread, or Sliver into any degreee of fineness which may be required."

This quotation substantially contains the gist of the specification, and there are three things to notice in it. First, a previous preparation of the fibre is named, this being a cleansing and carding process, by which a sliver or untwisted strand was provided. Second, that the rollers drew in the slivers and delivered them; and, third, that rollers revolving at different speeds were used, by which the strand was attenuated prior to twisting.

The date of the specification is important, as is also the evidence that yarn was actually spun in 1741 on a machine which was made by Wyatt, and that a manufactory in Northampton was actually started in 1748, in which frames, fitted with bobbins and spindles, *each independently driven*, were used. Lewis Paul, in 1758, patented a modification of the frame of Wyatt, a full description of which, with illustrations, is found in his specifications. Although there is evidence of use of these frames, it was only a partial one, and either from some defects in their construction, or owing to the lack of commercial ability, they fell dead. All that is necessary to say is that the conjoint and simultaneous operations of drawing and spinning were clearly indicated, and that at the time of Arkwright's first patent were fully published to the world.

This brings us to Richard Arkwright, whose claims to the credit of inventing the first frame "which spun without hands" are, to put it mildly, dubious. Arkwright was, as all the world knows, born of poor parents, in Preston, in 1732, and was given the trade of a barber. Stories are freely told of him which illustrate his determination to succeed commercially, among which is the well-known one of the "cut" in the prices of shaving from one penny to a halfpenny, in order to secure the business. From that occupation he rose to be a dealer in human hair, and having a knowledge of a process for dyeing it, was able to do a good business in those days of universal wig-wearing. Nothing is known prior to his thirtieth year about any mechanical pursuits, but it is known that in 1767 he was experimenting in constructional mechanics, pursuing that chimera —perpetual motion. In 1769 he patented his new spinning machine. In his specification he described himself inaccurately as "of Nottingham, clockmaker." It is known that in consequence of the treatment accorded to Hargreaves, Arkwright had gone to Nottingham accompanied by a Mr. John Smalley, of Preston—whom he had induced to aid him financially—and one John Kay, of Warrington, who was a clockmaker. It is important to note that Kay was undoubtedly intimate with one Thomas Highs, or Hays, of Leigh, the home of Arkwright's wife, for whom it is claimed that he was the first person to make an automatic spinning machine.

Arkwright's spinning frame is shown in Section in Fig. 1. It consisted of a rectangular frame, which had cross rails at the front, forming the bearing for the feet and necks of four spindles. Between the rails pulleys were fixed on the spindles, round which an endless leather band was guided, so that by the rotation of a hand wheel the spindles were driven. Mounted on the top of each spindle was an inverted flyer, and upon each, within the flyer, a bobbin was placed, which rested on the top rail. Round

the bottom flange of each bobbin a band or cord was placed, which acted as a brake, so as to enable the flyer to wind on the yarn during its rotation. Each of the flyers had formed on one limb a series of notches, so that by placing the yarn in these successively it was guided on a fresh part of the bobbin. By means of a vertical shaft motion was given to four pairs of rollers, which revolved at different speeds, and so drew the sliver, which was immediately delivered to the flyers and twisted. The bottom rollers were fluted, and the upper ones covered with leather and weighted.

We have here the prototype of the flyer spinning frame or throstle, but it is important to note that the action of the drawing rollers is substantially that of Wyatt, and, although the mechanism was improved, the simultaneous drawing and twisting was equally lacking in novelty. The additions necessary to make Arkwright's patented machine a success were substantially the reciprocal vertical movement of the spindle and the formation of an eye at the end of the flyer-leg. These enabled regular winding to be obtained, but substantially the other changes made were only in constructional detail and not in principle. Arkwright was fortunate enough to find financial backers who enabled him to make his machine a success, but there is very little doubt that it was only at the best as an improver on other men's work that he is deserving of credit. Wyatt and Paul had shown the way, and Arkwright did but perfect their work and bring it into commercial use. A more serious question is whether his efforts were not merely those of a commercial man, and in no sense those of an inventor. That he knew of the work of Wyatt is evidenced by his own admission, but there is more than a suspicion that he practically appropriated the ideas of Thomas Hays or Highs. Time will not permit of this point being gone into, and it is sufficient to state that two trials at law, one against Colonel Mordaunt in 1781, based upon a second

patent obtained in 1775, and a second one for the revocation of that patent tried in 1785 went against him. In the latter action the chief ground urged was that Hays or Highs was the real inventor, and that Arkwright stole it from him. Mr. Justice Buller pithily said that the defendant "had not a leg to stand on," and there is little doubt, on the evidence submitted, that this represented the truth. Arkwright's merits were principally those of a commercial inventor, who perceiving the weak points in existing machines can remedy them, and subsequently sell the machines so made. That his water frame as originally patented was a great stride forward there is no doubt, and it represents at once the legitimate successor of the Saxony or flax spinning wheel, and the predecessor of the flyer spinning frame in all its forms. It was the first continuous spinning machine which met with success and, although in some of its uses it is superseded by the ring spinning machine, it originated a type.

The history of the intermittent type of spinning machine is more interesting. It was remarked that the spinning wheel more generally used in spinning wool and cotton was one with a horizontal spindle without a flyer, and this was the foundation of all the machines of the "spinning jenny" type. There are two claimants for the honour of originating this machine, one, the Thomas Highs who was the alleged inventor of Arkwright's machine, and the other, James Hargreaves, of Stanhill, near Blackburn. It is a significant commentary on the remarks previously made as to the ripeness of the times that it is stated that the inception of Highs' jenny was the expressed inability of a weaver neighbour to find a sufficient supply of weft to keep him going, His invention was made in the year 1764, and the machine he constructed utilised the principle of the spinning wheel just named being shown in Fig. 2.

The spindles were placed at the front portion of the horizontal frame, and were driven by cords from a vertical wooden drum,

or cylinder, which was rotated by the handle shown. The rovings were held on skewers carried in a creel at the back of the frame, and each roving passed through an eye or loop of wire fixed about 18in. above the points of the spindles and skewers, and about halfway between them. The vertical posts at the back were carried up for a distance of about 8ft., and were grooved on the inside for the whole distance above the horizontal frames. A slide was fitted into these grooves consisting of two flat pieces of wood, opening and shutting vertically like a parallel ruler. This was called the "clove," and was drawn up by a cord coiled round a moveable bobbin or the axle of the drum. The axle was formed with a square portion, so that when the bobbin was on the square part of it, it was fixed, while when it was lifted by the hand of the spinner the axle could be revolved without turning the bobbin. When the slide had to be opened the bobbin was raised, and so remained until it was again necessary to spin. The rovings passed from the wire loops through the clove or slide, and thence to the spindle. After the closing of the clove, which secured the rovings, the bobbin was put on the square, and the handle rotated, thus performing the dual operation of rotating the spindles and raising the slide, and drawing the rovings between it and the spindle. When the full height was reached the bobbin was released from the axle, but held by hand so as to keep the clove stationary, and maintain it in its highest position until the rest of the twist was introduced. Then the bobbin was replaced, and the drum rotated so as to lower the clove and wind the yarn on to the spindle. The claim for the priority of the invention of Highs' is made very strongly by Mr. Richard Guest, from whose book the descriptions and illustrations are derived, and a strong *primâ facie* case is made out by him. The matter is not very important, as it is likely that both inventors worked independently.

James Hargreaves, a weaver, who lived at Standhill or Stanhill, near Blackburn, conceived in or about 1767, a similar idea, while living in his little cottage, which, as it exists to-day, is shown in Fig. 3.

Hargreaves' spinning jenny (shown in Fig. 4) consisted of a wooden frame sustaining the bearings of the driving pulley, by which a roller or cylindrical drum placed near the back of the frame and crossing it transversely was driven. The spindles were borne in a frame also extending across the machine, and upon each was placed a grooved warve as at the present day. Bands were stretched over the tin roller and warves, so that on the rotation of the pulley by hand all the spindles were set in motion. In a double banked creel—probably single banked at first—previously prepared rovings were placed, the creel being so arranged that the rovings could be easily drawn from the spindles or pegs. A sliding carriage consisting of two rails the full width of the machine, and fixed in blocks provided with small runners, traversed upon slides fixed to the framework of the machine for a length which was limited by the needs of the case. In order that the roving might be firmly held both by the upper and lower cross rails they were formed with reciprocal grooves and projections. The rails were so arranged that a grip could be established, while they were continuously detached by the pressure of a small spring. Immediately adjoining the spindles a roller or rail flanged at each end and capable of rotary motion on its axis was placed, its rotation being secured by a cord from the front of the machine. Fixed in each of the flanges at equal distances from the axis of the roller and near the periphery of the flanges was a wire which, when the roller was rotated, could be pressed upon the several threads so as to force them down. As the pressure was removed the yarn or thread, naturally tending to assume a straight line, rose on the spindle, and so was guided upon it in regularly ascending coils.

In working the jenny, after the roving was passed through the gripper and attached to the spindle, the carriage was drawn back until the necessary length of roving was laid between it and the spindle, when it was gripped by means of the left hand. The spinner then rotated the driving wheel with one hand, and with the other slowly drew back the carriage until it reached the limit of its traverse. During this time the roving was being drawn and twisted simultaneously, and was also being evened by reason of the tendency of the thin places to receive the twist while the thicker ones did not take it so readily. By a further rotation of the wheel, after the termination of the draw, any desired twist could be introduced. As soon as this was completed the spinner reversed his wheel, simultaneously gently rotating the roller so as to bring the wire on the top of the threads, and thus, as the yarn was during the first portion of the backward movement released from the spindle, it was gently forced downwards. The carriage was simultaneously pushed in, and so by the combined further backward rotation of the wheel and spindles, the depression of the wire, and the inward movement of the slide, the winding operation was completed.

There are some likenesses and differences in these machines. In both a certain length of roving was delivered and twisted separately; and in both the draft was obtained by the recession of the clove from the spindles. In one case, however, the movement of the clove was the work of the spinner, which possessed the advantage of allowing him to give the yarn a final stretch after spinning, while in the other the whole operation was simultaneous and automatic.

It will be of some advantage if, before proceeding further, a brief outline is given of the operation of mule spinning, which, although familiar enough to some members, is not so to others. The mule, see Fig. 5, which is a diagrammatic representation of the essential parts of it, spins the yarn in the form of a

cop C, which, beginning low down on the blade of the spindles, is gradually built up. The spindles are all borne in a carriage O, which is given a reciprocal movement to and from the rollers E which deliver the roving. All the spindles, and other moving parts of the machine, are driven by bands from one central point, where the driving mechanism is placed. Assuming that the operation is about to begin, the carriage is near the roller beam, the rollers are still, and the spindles are also at rest. The transfer of the strap on to the fast pulley sets the whole of the parts into motion, the rollers and the spindles revolve, and the carriage moves out, so that as the roving is delivered by the rollers, it is twisted and also drawn a little more. This is the first stage of twisting and drawing. When the carriage ceases its outward motion, the rollers are stopped, and the direction of rotation of the spindles is reversed in order to uncoil two or three turns of the yarn, which are wound on the spindles, above the point of the cop. This is called "backing-off," and, as the yarn is released, two guide wires come into operation, one N passing the yarn down towards the base of the top cone of the cop, and the other M acting as a kind of a compensator. These wires are called respectively the "winding" and "counter" fallers. When backing-off is completed the carriage begins to run in, and by means of the pull of a chain attached to an oscillating arm at one end, and to a barrel geared to the spindle drawing roller at the other, the spindles are revolved so as to wind on the yarn. This operation ceases when the carriage assumes its innermost position, and during its continuance the winding faller, which is controlled by a vertical lever sliding on a long rail of special profile, is given the necessary upward movement to guide the yarn on to the correct portion of the cop. At the termination of winding, the operation commences *de novo*. It will be necessary to recur to the winding operation at a later stage, but this brief outline will enable it to

be understood that there is a complete cycle of movements in mule spinning, and that it is therefore necessary to provide for the changes taking place at the proper time and with unfailing accuracy.

By the aid of this brief outline it can be seen how far the two primitive forms described contain the germ of the modern machine. In the first place, spindles were, in each, vertically sustained, with the rove passing on to them nearly at right angles, rotated simultaneously from a roller or cylinder, the movement of which could be reversed at will. Second, there is the simultaneous twisting of the yarn, and its attentuation, caused by the outward or upward movement of the clove. Third, in the Hargreaves machine there was the operation of backing off, accompanied by the slow descent of the faller wire, so as to guide the yarn on to the spindle. Fourth, the gradual winding on of the twisted yarn as released by the inward or downward motion of the clove. All these operations were necessarily of a manual character, and partook of the failings incident thereto. There was no guarantee, for instance, that each length of roving treated would be twisted quite equally, or in the Hargreaves' machine drawn at the same speed, or wound in identical coils.

The chief defect of both these machines was that every length of roving which it was desired to spin or twist had to be first measured off and then secured. It was, in fact, an operation analogous to the action of the hand-spinner in drawing from the heap of carded material a certain quantity, which was reduced by the fingers of the spinner to the required degree of tenuity. When the idea of continuous delivery had taken possession of the minds of men, such a crude procedure could not continue, and it was soon demonstrated that it was possible to furnish a continuous and uniform supply of roving, drawing it in the process. Hargreaves showed that the

material, after the introduction of a twist, could be still further attenuated during the operation. It remained for Crompton to prove that it was possible to combine within one machine apparatus which reduced the roving during delivery, attenuated it still further in the early stages of twisting, twisted, and wound it into a convenient form. Let it be granted that the full knowledge of all these parts existed, the merit of their combination remains, and it is this notable act which stands for ever to the credit of Samuel Crompton.

Samuel Crompton (Fig. 6) was born near Bolton, and it was in the room at the corner of the building known as Hall i'th' Wood (Fig. 7) that he worked out his invention. It may well be that the idea of using rollers for the purpose of drawing the rove was independently evolved, but be that as it may, the fact remains that the idea of a pair of rollers, of which the bottom one is fluted and the upper one covered with leather or some other soft material, is common to both Arkwright and Crompton. In the machine as made by Crompton (Fig. 8) the spindles were borne in a carriage running upon rollers, to which a reciprocal horizontal movement of 54 inches was given by means of an endless band. The rovings were delivered by the rollers during the time the carriage was being drawn back by the spinner, during which time he was rotating the spindles and putting in the twist. The speed at which the carriage is being drawn back could be arranged to be a little quicker than that of the roller delivery, so that here is the carriage gain, which is now recognised as so important, and the same power existed of giving to the carriage a slight receding motion as the final twist was introduced, thus allowing for the shortening effect thus produced. By means of an endless band a drum in the carriage was rotated from which the spindles were driven and the rollers were also driven from the central axle. The second draw by the carriage gain is important, for improvements in the preparatory

processes having provided the spinner with a rove which is nearly perfect, the benefits derived from a draft during the time that the final twist is introduced are most marked. For this reason, although the production of yarn is higher in the case of continuous than intermittent spinning, there are still many industries in which the yarn produced by the latter system is wisely preferred.

One cannot read the life history of Crompton without recognising that without undervaluing his own invention he was still quite unmoved by the commercial aspects of it. Unlike Arkwright, who possessed more of the mercantile than the inventive genius, he was content to do his work well, and was indifferent to any other consideration. In his own words: "It was not in my power to keep it and work it, and to destroy it was too painful a task, having been four and a half years, at least, wherein every moment of time and power of mind, as well as of expense, which my other employment would permit, were devoted to this one end, the having good yarn to weave, so that to destroy it I could not." The story of its development as told by Mr. Kennedy and others, is at once an instruction and an encouragement. The first trial with one pair of rollers, the development to a second set, the endeavour to form flutes by putting in dents of reed wire, and many other known facts, show the difficulties with which he laboured in an age when tools were few and rude and his means scanty. It is almost as true of him as it was of Burns that "he asked for bread and they gave him a stone," but the enduring monument is not to be found in the handsome statue erected in Bolton, but in the almost miraculous cheapening of the product which has enabled thousands to obtain shirts who never had them, and has opened the door for the production of a vast range of fabrics never previously thought of.

It is not possible now to go through the various stages in the development of the mule. Many inventors worked at it, and in

a short time machines containing 600 spindles were in existence. William Kelly, of Lanark, applied power to the machine, and invented, in a crude way, the rail which guides the winding-faller wire, and to which the name of the copping rail is given. But up to 1825 it remained substantially a hand machine, although there were many attempts to overcome the difficulties of the case. The chief trouble was found in the rotation of the spindles during winding and the guiding of the winding-faller wire. It need hardly be pointed out that as the cop is conical, the speed of the spindles must be varied as the yarn is wound in ascending coils, and that upon the existence of an exact relation between the spindle velocity and the position of the faller wire, depends the correct winding. William Eaton was the first man who recognised this factor fully, and by ingenious mechanism he obtained three results—a variable speed of the spindles during the run in of the carriage; in winding the yarn it was first guided from nose to base and then from base to nose; and finally made the connection between backing-off and the downward descent of the winding faller rigid and automatic. Although Eaton's mechanism was unsuccessful, it showed, in its inception, a thorough grasp of the situation, but left untouched the automaticity of the changes. The chief points which required the skill of the inventor were two-fold. First, the perfecting of the winding so as to establish the correlation of the movements of the spindle and faller with ease; and second, the addition of a motion which would render the machine entirely automatic in its changes.

As it stood when Eaton left it, it was nearly perfect. The outward draw of the carriage; the delivery and stoppage of the rollers; the inward draft of the carriage; an automatic backing-off; the maintenance of the correlation between the winding velocity of the spindles and the ascent and descent of the faller; the absorption of the slack yarn produced during backing-off;

the gradual elevation of the faller's traverse, and its requisite up and down movement—all these had either been actually effected, or in some degree effected. But the appliances for the purpose were ineffective, and required replacing and supplementing by means which would make the requisite changes of action automatically. To combine previous knowledge with more perfect mechanism was a formidable undertaking, and yet in a few weeks the inventive genius of one man, to whose work feeble justice has been done, proved capable of furnishing a solution having the supreme merit of not only obviating the existing difficulties, but of furnishing a base upon which all other succeeding machines have been effected. It is to the gigantic mechanical genius of Richard Roberts we owe the self-actor, and some day justice will be done to this triton among the minnows of the inventive waters. It was, of course, a great gain to have clear ideas on the subject, but between that and the production of mechanism to make them operative, there is a great gulf fixed.

The limits prescribed for this address will not permit a detailed account to be given of Roberts' mule (Fig. 9), but the chief changes made may be detailed. Eaton had shown that it was possible to reverse the motion of the driving shaft—called the rim shaft—on which were fixed the grooved pulleys by which the band was driven. Roberts hit upon the idea of having three pulleys on the rim shaft, two of which were loose and one fast. One of the pulleys drove the spindles when in work, and the other during the period of backing-off rotated the rim shaft in the opposite direction by means of a second strap. The loose pulley was always driven in the normal direction by a slight overlap of the main driving belt, and in its turn rotated a small friction pulley, which at intervals drove a side shaft placed with its axis parallel to the rim shaft. This "cam shaft" remains to-day the instrument employed in most mules

in "making the changes," that is, bringing about the various stages in the cycle. It is not practicable, without going into full detail, to make quite clear what Roberts did, but the following brief account will serve.

He applied a shaft *b* on which cams were fixed, which, when they were engaged, as they were at intervals automatically regulated by the action of the various parts, took out of or threw into gear the requisite mechanism. The driving straps were regulated by its means, and the roller shaft clutch disengaged at the end of the outward run of the carriage. As the drawing-out gear was driven from the roller shaft the motion of the carriage was correspondingly arrested. The cam shaft also actuated the taking-in motion on the locking of the faller, and caused the carriage to be drawn in; and finally it was actuated so as to make all the parts resume their positions to recommence spinning. Thus the addition of this single part rendered all the operations of the mule automatic, and no simpler or better means have since been found.

This was by no means the only improved part in the patent of 1825. Roberts added a click catch and ratchet on the drum shaft, which geared during the period of backing-off only—that is, when the motion of the drum was reversed—and by means of a snail and chain drew the faller-locking lever into its locked position. The counter-faller shaft was also provided with weights by means of which the tension of the yarn could be exactly balanced without strain. The faller lever and bowl, running on a shaped plate, had been used by Kelly; but there is a further development, for which Roberts deserves all credit. He combined the ideas of giving the necessary traverse to the faller by the ascent and descent of a bowl in the faller lever along a double inclined surface, and that of the gradual change in the vertical position of the surface on which the bowl rests. It is due to Roberts to say that in his first specification of 1825

he distinctly disclaims novelty for the parts, and only claims it for the combination. But, in effecting the combination, he introduced a novelty in the method of sustaining the copping rail. This, in Kelly's device, had been a fixture; in Roberts' arrangement it was mounted, as it is to-day, on inclined shaper plates, which were moved by a screw operated every time the carriage ran out. The form subsequently given is that which is now familiar, and the shaper plates were arranged so as to give the gradual and necessary elevation. The locking of the faller, therefore, gave successively a different initial point for each series of coils, and this simple solution of the difficulty had the advantage over that adopted by Eaton, that a straight surface was used, and not a curved one.

The method of winding adopted by Roberts in his first patent was by no means perfect, the variable speed of the spindles being obtained by an application of friction, always a risky plan. Accordingly, in 1830 he patented that ingenious device, the winding quadrant, which completely solved all difficulties. Without describing the exact application of the quadrant to Roberts' mule, it will be sufficient to say that the principle is shown in Fig. 10. The quadrant consists of a straight hollow arm, which has within it a nut fitting on a screw extending longitudinally of the arm. By automatic action the nut is gradually moved further from the centre until when what is known as the "cop bottom" is completed—that is, when the full diameter of the cop is reached—no further movement takes place. As the carriage moves in the arm is positively moved forward by a pinion engaging with the quadrant, and the pull upon the chain is thus minimised, being greater as the end of the run-in is approached, the yarn at that moment being wound on the smallest diameter, implying the most rapid rotation of the spindle at that point. The chain is wrapped on the winding barrel, by the rotation of which the spindles are driven, so that

when a pull is exercised on it the spindles are rotated. The quadrant, as a glance at Fig. 10 shows, is practically a crank arm, and the forward movement of the nut therefore diminishes as the arm approaches the horizontal. If the drums from B to C—looking carefully at the lines immediately below each circle, which show the quantity of chain unwound—are compared with those from H^1 to N^1, it will be seen how the upward or outward movement of the nut affects the problem. What Roberts had to do was to devise a means by which the action of the faller could be so combined with the speed of the spindles as to give an equal winding at all parts of the cop. In the quadrant, with its forward moving arm and its outwardly moving screw, the solution of this difficult problem was found, and had he done nothing else than invent this beautiful adaptation of means to an end, he would have earned lasting fame. But this was not all the full list of the novel features, these being as follows:—The automatic changing of all the motions; the depression of the faller to the nose of the cop prior to backing-off; the depression of the faller during the backing-off by means of a click motion and snail; the locking of the faller in position; the combination of a faller lever and an adjustable copping rail; the regulation of the latter by shaper plates; and the control of the winding by a quadrant arm, practically a fusee, so as to give a variable motion to the spindle during winding. These are all substantially to be found in the modern mule, and formed a gigantic achievement for one man, and were illustrative of his great mechanical genius. Without undervaluing the work of subsequent inventors, and more especially those skilful constructors who have remodelled and strengthened the mule, so as to make it the perfect instrument which it now is, a special meed of praise is due to Richard Roberts, who gave it its present form at a time when its capacity had not been tested, and when it was quite

impossible to draw on the stores of knowledge which have since accumulated.

During the period in which the spinning machine proper was being perfected a like process was going on with other machines. It became evident at a very early date that in order to obtain the full effect of the improved spinning machine it was imperative that the rovings should be made as perfect as possible. The cotton as received required, in the first place, to be cleansed and then drawn out into a sliver which could be readily spun. These operations were gradually subdivided, and the present series of machines evolved. The willow beating machine, which was at first merely a cage made of rods, was gradually improved by the use of a cylinder to beat the cotton, grids against which it was flung and through which the dust fell, and a fan to remove some of the dust. The scutching machine was invented by Mr. Snodgrass, of Johnstone, and, by the date of Roberts' second patent, 1830, had the perforated cages and lap machine added, by which the beaten fleece was formed into a rolled-up sheet. The carding machine was invented by Lewis Paul in 1748, and, although crude in form, possessed the cylinder covered with carding points and a stripping comb. Mr. Peel, the founder of that family, introduced a carding machine of this character, which, in 1772, was improved by the addition of a feeding apron by John Lees, of Manchester, and in 1774 Arkwright devised means for forming a lap to feed the cotton and applied a second cylinder or doffer to strip it. At this period there are three essential elements present, viz., continuous feeding, carding, and stripping. Shortly after, the doffing comb, by which the fleece is removed from the doffer, was invented, the merit of this being claimed for Arkwright, Hargreaves, and Highs. In either case, the fleece which is taken off in a thin web was gathered into a sort of rope or sliver, and collected in a can. The machine was provided with

card-covered flats superposed above the cylinder, and which could be removed for cleaning. The can into which the sliver was delivered was revolved so as to put in a slight twist; but early in the present century the eccentric guide trumpet and revolving can known as the coiler was invented by David Cheetham, of Rochdale.

Very early in the history of the industry the drawing frame, which is simply a series of rollers revolving at various speeds, was invented and used, and it was not long before the drawn slivers were subjected to a twisting action prior to placing them in the spinning machine. Arkwright used a modification of his water frame, but the difficulty of rotating the bobbins at a differential speed as the bobbins filled was for a long time nearly insuperable. In 1826, Mr. Henry Holdsworth, of Manchester, applied a form of epicyclic train which solved all difficulties, and which has since been in substance adopted for all roving frames. It only remained to divide the operation of drawing between two or three machines, and the classification which now obtains resulted.

It need hardly be said that since 1830 the machines have been considerably improved, but the improvements have been in the details and not in principle. After the cleansing stage is finished the principle of continuous draft by rollers is the one which forms the central feature in the treatment of the material. Slowly the sliver formed on the carding engine is attenuated, and the twist given to it is merely sufficient to enable the roving to be drawn from the bobbins. The invention of "drawing without hands" is the one which permeates the whole of the modern system, and which is manifested in all the machines used after carding. It is necessary to deal with this part of the subject briefly, because there is another section which demands attention.

The loom in a more or less crude form has existed as long as human records can be found. In the hieroglyphics of Egypt

representations of looms have been discovered, and right through succeeding centuries the art can be traced. Further, it is evident that, crude though the instrument might be, the skill of the weavers enabled them to produce wonderful effects. In the ancient looms the plan of arranging the warp threads so that they could be divided to form a "shed" or space through which the thread of weft or woof was thrown was followed, and although many constructive changes took place, it was not until 1733 that any great improvement was made. Up to that date the shuttle was thrown from one side of the loom to the other by hand, necessitating the attendance of two workpeople. In the year named, John Kay, a native of Walmersley, near Bury, and who was the inventor of metallic reeds, invented the fly shuttle, a loom as made by him being shown in Fig. 11. At each side of the "batten" or course on which the shuttle ran Kay formed two shuttle-boxes, in each of which a spindle was fixed so that a piece of leather known as a "picker" could slide. These pickers were connected by a slack cord, to the centre of which a "picking stick" or handle was attached. When the shuttle was in either box a smart pull on the cord in the inward direction caused the picker to slide and strike the shuttle, thus impelling it across the loom and throwing it into the opposite shuttle-box. The warp threads are threaded through light frames called healds, the vertical strings of which raise them. According to the number of healds used depends the number of threads raised by each, but, in weaving plain cloth, one half of the warp threads are raised by one heald and the other half depressed by the other. These healds in the old loom were operated by treadles worked by the feet of the weaver, and as the warp threads were stretched between a roller containing the warp at the back of the loom—called the warp beam—and another one at the front—called the cloth beam or roller—the raising and lowering of the

warp made a sort of <> shaped opening through which the shuttle was thrown. The weft thread being held in the shuttle so that it would be drawn out, and being fixed in the cloth, the result was that one thread of weft—or a pick—was laid across the warp everytime the shuttle was thrown. By now operating the treadles the elevated warp threads were depressed, and those which were depressed elevated so that the weft was locked by being passed over and under alternate threads. By means of Kay's arrangement one man could work a loom. The batten, which acted as a course for the shuttle in its passage, also carried a reed, or comb, through which the warp threads were passed, and by swinging which, after the passage of the weft and before the change of position of the warp threads, the weft was beaten well up to the preceding picks. Thus, by one hand the weaver made the picks, by another he beat up, and with his feet he worked the treadles. Kay's invention met with strenuous opposition, and although partially adopted in Yorkshire, he had, as depicted in Mr. Madox Brown's picture in the Manchester Town Hall, to fly for his life in consequence of the ignorant persecution of operative spinners and weavers. Kay never received any adequate reward for his inventions, although the fly shuttle revolutionised the condition of the industry. In 1760 his son invented the drop box, by means of which two or three shuttles containing weft threads of different colours could be used, thus enabling coloured calicoes to be woven.

It is obvious that if by two healds the warp threads can be divided into two equal parts it only requires the application to each thread of some instrument which will lift or depress it to obtain any desired arrangement of pattern. Thus, if the warp threads are differently coloured in sections, and weft threads of different colours also used by the application of the drop-box, there is a limitless power of combination given, examples of which are seen in the wonderful specimens of woven fabrics with which

you are all familiar. This step to independent control of each thread is commonly ascribed to Jean Marie Jacquard, who, in the course of eleven years 1790—1801, completed the machine which bears his name. It is not possible to deal in detail with the invention, but its chief features are as follows:—The control of each warp thread by a cord attached to a vertical hooked wire, which can be lifted by a reciprocating knife. The selection of the cords to be lifted was made by means of horizontal needles, which pushed them out of the way of the ascending knife. The operation of pushing in the needles in the requisite order by means of a chain of cards, suitably perforated and passed over a barrel, to which a reciprocating inward and outward motion is given, and also during the outward motion a partial rotary movement, which brings the next card of the series into position. When a hole in the card came opposite a needle, the latter remained undisturbed, and the hook controlled by it was left in position to be lifted. If, on the other hand, an unpunched part of the card came against the needle it was pushed in, and moved the hook out of the way of the knife. By suitably punching the cards, therefore, the warp threads could be lifted in any desired order. There is little doubt that although Jacquard perfected the machine, the pierced cards were anticipated by Bouchon in 1725, and by Falcon in 1728; and the combined reciprocating and rotative movement of the cylinder, and the rising and falling knife, by Vaucanson in 1745. Jacquard's merit was in the full combination of all the elements, and, so far as this type of warp mechanism is concerned, practically nothing has since been done but improve his arrangement. It may be said also that the same principle of selection has been applied to the mechanism of the drop-box, so that it is now quite possible to actuate both warp and weft threads in accordance with the necessities of the pattern. As a proof of the wonderful power given by this mechanism it is mentioned by Barlow that in the International

Exhibition, 1873, Messrs. Norris exhibited a hand-loom weaving a silk damask. There were 29,088 warp threads, and the design was 28 inches long, 9,812 cards being used to complete the pattern.

The evolution of the loom was aided by the application of power to it, this being the work of Dr. Edmund Cartwright, in 1785. Cartwright was a clergyman, and constructed his first loom before he made himself familiar with the operation of weaving. After he had obtained his first patent he saw that much improvement was wanted, and in 1787 took out a second patent, which may be looked on as embodying his settled purpose. It was full of ideas which have since been perfected. Among these was a warp and weft stop motion, a motion to take up the cloth and let off the warp as required at a regular speed; a method of shooting the shuttles by rods actuated by springs, and temples for keeping the woven cloth in lateral tension. Cartwright's loom was complicated, and subsequent inventors applied themselves to perfecting it. Bit by bit the loom was improved by various inventors. It was apparent that, as the healds were raised and lowered by means of cards attached to hinged treadles, one of the first results of the application of power to the loom was found in means by which this operation was rendered a mechanical one. The obvious solution was the employment of some form of cam or eccentric which, by its rotation depressed or elevated the healds in accordance with the manner in which the treadle levers were coupled to them. From this simple solution has sprung all the elaborate means of actuating the healds, which for a great range of fabrics remain the operative instruments in the formation of the shed. It is clear that by suitably arranging the cam course, one rotation of the shaft can be made to give several movements of the healds, and the great family of treading motions are all founded on this principle of a rotary cam acting on a hinged lever.

In like manner the batten or lathe of the hand loom, being a hinged frame, could be readily operated by the rotation of a shaft. Thus the main shaft of the machine was fitted with cranks, the batten was hinged from the bottom instead of the top, and being coupled to the crank shaft by connecting rods, received the necessary reciprocal movement. The construction of the slay, which is the modern representative of the batten, has been improved, the arms on which it oscillates being separately attached, but in essence it is the same piece of mechanism. The third portion of the mechanism which required special means to work it was that actuating the picker. By slow degrees this was evolved, until the present form of a rod or shaft, rocked by a rotary cam in such a way as to have a sudden movement, was evolved. By a strap attached to the picker and an arm on the shaft, the picker derived its quick movement so as to act percussively on the shuttle.

All these motions were the result of the efforts of numerous inventors. It is obvious that as the cloth is woven it is necessary to draw the warp forward at a definite rate, which shall be in exact accordance with the number of picks of weft to be put in each inch of length. Numerous attempts were made to attain this, and it was aimed at alike by controlling the rotation of the warp beam and that of the cloth roller. The former was roughly but effectively controlled in the hand loom by a weighted rope coiled on its axis, and this, for some purposes, has not been improved on. In 1822 Richard Roberts perfected a power loom, which contained, among other things, a take-up motion by which each beat of the slay was made to actuate a ratchet wheel, the rotation of which was communicated by gearing to the cloth roller. The power of adjusting the stroke of the pawl and of changing the value of the gearing rendered this motion unique, and it is substantially the basis of all successful take-up motions of the present day. This is

another instance of the completeness with which Roberts grasped the mechanical needs of the case. The patent contained a number of other excellent features, and constructively was as perfect as the self-acting mule. By the year 1830 it may be said that spinning and weaving machinery had taken concrete form. The division of operations was marked in both departments, for just as the preparation of material for spinning was the work of a well ordered series of machines, so in weaving the preparation of the yarn for the loom was equally elaborated.

Were it not that the time limits of an address of this character are reached it would be easy to extend it. It is impossible to close, however, without saying a few words on a side of the question which is of deep interest. One of the first results of the invention of the various machines which have been referred to was the destruction of the old system of working and the substitution of a new one. The household industries had been gradually proving inadequate for the needs of the nation, and when the adoption of the fly shuttle led to an enormous increase in the demand for yarn it could only be met by the new frames. The development of the steam engine released manufacturers from the necessity of depending upon water power, and speedily led to an increase in the size of the machines, until in 1820 mules of 500 or 600 spindles were in extensive use. To employ these it was necessary to collect under one roof the whole of the machinery necessary for preparation, and so the independent spinner and weaver became transformed into the factory "hand," and the system of organised industry arose. From this system has arisen by slow degrees that extension of popular liberties which has rendered this country the freest, and on the whole the most prosperous which the world has seen. No one can deny that in the main the standard of comfort of the people of this country has been enormously raised, and although in its early stages the system

was used tyrannically and cruelly, our statesmen fortunately soon realised the force of Goldsmith's words—

> "Ill fares the land to constant ills a prey
> Where wealth accumulates and men decay."

The efforts of our machinists and engineers have been directed to the improvement of the instruments of production, and these in turn have led to enormous improvements in the structures used to contain the machines until working conditions are approaching the ideal. There is a marked improvement within the last generation in the physique of cotton operatives, and although much remains to be done there is reason for congratulation. It is proven beyond doubt that the industrial victory rests with the population which is best fed and best paid. In all industries, and especially those requiring skill and knowledge, this is an established axiom. Despite many threatenings and warnings, if we take care to see that our population is well fed and intelligently trained, then, industrially, we may say with confidence—

> "If England to herself be true, come all the world in arms, and we will shock them."

VOTE OF THANKS

Mr. Thomas Ashbury said, after hearing the very elaborate address they had received that night, he had been struck by the beautifully concise form in which it had been prepared. They had had placed before them in a graduated manner an historical record, which would certainly be of infinite value for all time.

He might say that the majority of the members anticipated hearing from a gentleman of the experience and knowledge of their President, something which would be worthy of their attention, and he was sure there were none disappointed. It

augured well for the success of the coming year. He had great pleasure in proposing that the hearty thanks of the members be tendered to the President for his inaugural address that evening.

Mr. T. DANIELS remarked that he had much pleasure in seconding the resolution, as he had been much interested in the subjects referred to by the President. The patriotic peroration of the President had certainly excited in him a martial feeling, and after hearing those concluding words he certainly felt inclined—if it was not too late—to join the Army. (Laughter.)

Seriously, however, he coincided with Mr. Ashbury's prognostication of a successful presidential year, and indeed personally felt that no support would be wanting on the part of the Council and members to attain that end.

The resolution was passed with acclamation.

The PRESIDENT in replying said he had chosen his subject because he thought that there were very few who were familiar with it, and that they might learn something of the historical development up to Roberts' time. He had not gone beyond 1830 for the reason that with the exception of one or two machines, the main form was then fixed, and all that has since been done has been simply in constructional details.

He might have almost made an interesting paper purely from a statistical point of view, because that was really the way in which to gauge the marvellous progress made. Robert's mule, perfect as it was, had nearly doubled its production since its inception, this being simply due to the efforts of mechanical construction, until to-day it stood as one of the most wonderful machines in the textile world.

Although their American friends seemed to think that the mule was a doomed instrument, he did not believe it was any more doomed than any other machine. It will find a place for many years to come, because although we cannot prophesy that nothing will turn up to efface it, at present there was apparently little movement in that direction.

He thanked the members for their cordial reception, and for their promised support, because without it, it would be impossible for him to fulfil his duties and advance the Association's interests, as was desired.

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10 Plates follow Illustrating this Paper.

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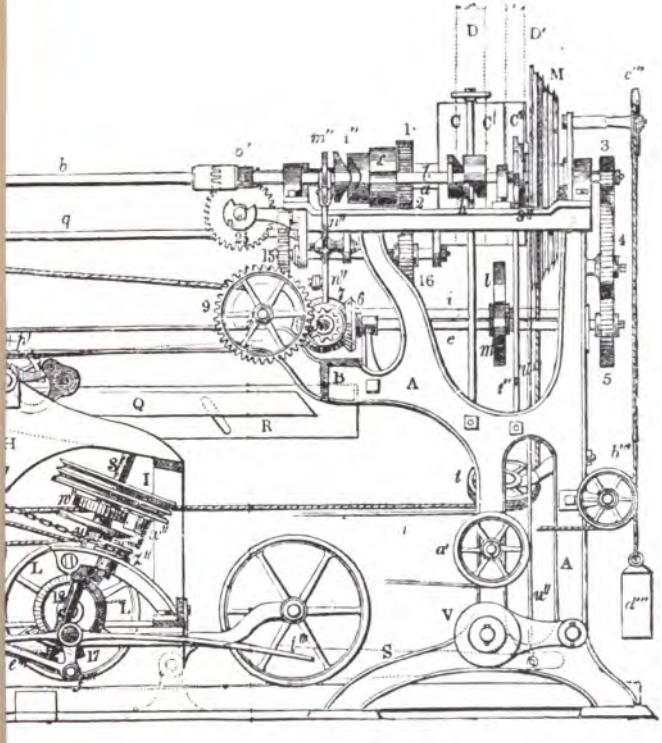

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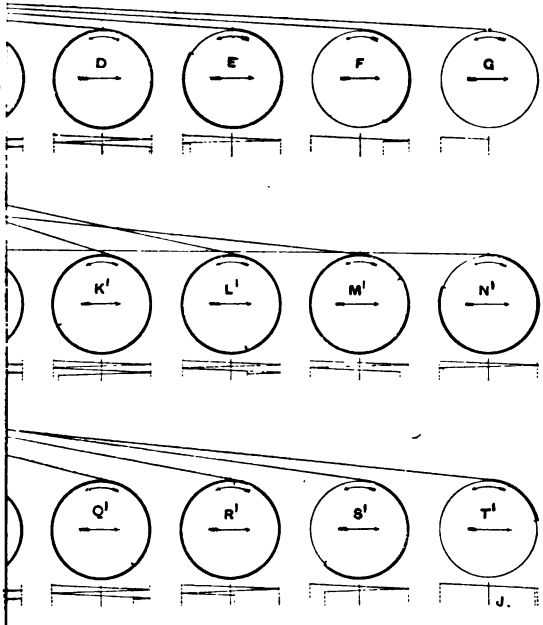

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R. H. TWEDDELL, M. INST. C. E.

ON THE TRANSMISSION AND APPLICATION OF POWER TO MACHINE TOOLS, ETC.*

WRITTEN BY THE LATE

Mr. R. H. TWEDDELL, M.Inst.C.E.

OF LONDON.

READ SATURDAY, 25TH JANUARY. 1896,

By Mr. T. ASHBURY, Manchester.

The author would never have ventured to give a paper on "Machine Tools" in Manchester (the home, it may almost be said, of this branch of mechanical engineering) did he not propose to confine himself principally to those worked by hydraulic pressure. The experience, however, of Manchester Engineers in the application of hydraulic pressure to cotton and other presses (although in their mode of working as a rule essentially different to the system about to be described) will, he hopes, ensure him a considerate hearing.

Previous to 1865, or say 30 years ago, it may safely be said that anyone would have searched the advertising sheets in the leading engineering papers in vain for any *Hydraulic* Machine Tools, and it is with somewhat mixed feelings that the author contemplates their present number. This practical proof of the soundness of any system is not one to be disregarded. People do not continue to advertise unless they thereby obtain orders; and, even in this technical age, owners of works and their managers are apt to be as much influenced by what has already been done by their neighbours, as by diagrams

* It should be noted that this paper is the original draft of what probably would have been a fairly exhaustive paper on the subject, but is unfortunately incomplete owing to the sudden decease of the Author.—SECRETARY.

and mathematical theories. This somewhat unusual line of argument is adduced as a contributary proof at all events of the correctness of the principles on which the system about to be described is based.

There were, of course, hydraulic tools in use at or before the period referred to. One of our leading locomotive engineers recently told the author that out of the many hundreds of supposed new inventions submitted to him, he seldom failed to find most of them anticipated in one or other of the volumes of the *Mechanics' Magazine* commencing in 1823. In 1866 this same *Mechanics' Magazine* published a description of a hydraulic machine tool, designed and patented some time before by the author, for expanding tubes in boiler tube plates. In the year 1868, Mr. William Boyd read a paper at Newcastle-on-Tyne, on the subject of Hydraulic Riveting, being the first paper on this question read before any scientific society, a description of a hydraulic riveting machine, designed by the author, forming part of the paper; Messrs. Thompson, Boyd & Co., of Newcastle-on-Tyne, having made this hydraulic riveting machine for themselves as an experiment, intending if successful to make them for sale. Prior to this, in 1863, the author patented the portable Hydraulic Expander above referred to, and so far as he knows this was the first occasion when, with a pressure of one ton per sq. inch, water was conveyed by means of flexible copper pipes to a machine, free to move about inside and outside a boiler. It was in connection with the manufacture of this tool that he paid his first visit, now 32 years ago, to this district to a Mr. Needham, at that time in a considerable way of business at Dukinfield.

The years 1866 to 1873 saw a large number of Stationary Riveters successfully introduced, and the success of the system firmly established. Flanging and Stamping Presses and Hydraulic Shears were also introduced in considerable numbers

during this period. In 1871 the Portable Riveter was designed and patented by the author. The manufacture of this entirely novel type of machine tool was, however, declined by several engineers, including those who had been so successful with his stationary machines, as visionary and impracticable. The author was at last fortunate enough to secure the co-operation of Mr. James Platt, a Lancashire engineer established at Gloucester in partnership with Mr. Fielding, also the author believes, from this district. They undertook to make it. It is quite certain, however, that neither the author nor Mr. Platt had any idea of the troubles in store for them. The difficulties were not so much due to its special hydraulic features as to the difficulty at that time in obtaining suitable steel for the arms, getting sufficient rigidity combined with lightness, and arranging all the various connections to lead the water from the Accumulator to the portable Riveters suspended many feet in mid-air. However, in 1873, the Primrose Street Bridge, over the Great Eastern Railway, London, was completed, being the first bridge mechanically riveted in *situ*. Just as most of the initial difficulties were surmounted Mr. Fielding died, and in the many new designs and applications introduced and patented since then, his son, Mr. John Fielding, has been closely identified. But if 1873 was an important epoch in hydraulic riveting, the year 1878 afforded the first opportunity of fully showing the economical advantage of the hydraulic system as a means of transmitting power to machines of many different kinds spread out over great distances.

In consequence of the author's representation, and the assistance of his colleague Mr. Henry Chapman, of Paris, Mons. Marc Berrier-Fontaine, the engineer at the French Arsenal at Toulon, authorized the laying out of the whole of their new works on the author's hydraulic system; the machinery being supplied by the Hydraulic Engineering Co.

of Chester, and Messrs. Fielding & Platt of Gloucester. From that time the hydraulic system of machine tools was firmly established, and occupies in its proper field an unassailable position by reason of its economy and convenience of application.

It may not be amiss when electrical transmission has such enthusiastic advocates, to point out that there were heroes before Agamemnon, and that, substituting the word hydraulic for electric current, their arguments are all anticipated by those used years ago in connection with hydraulic transmission of all kinds. One of your members in the course of a discussion in these rooms referred to the Goddess "Electra," who by the way was Agamemnon's daughter; now although nothing much amiss as things were then, is known against her, her mother as you doubtless remember took a most unfair advantage of her father by sewing up the sleeves of his tunic, and while he was engaged in the difficult task of getting into his garment, under such adverse conditions, killed him. In the author's opinion there is a large field open for the application of electric motors to machine tools not only on the score of transmission of power over great distances, but also its convenience when the question of working sections only of a shop, or a single machine placed amongst many others, is to be considered. It will be well for works' managers to proceed cautiously in adopting electricity or they may soon be, metaphorically, struggling in tunics sewed up for them by too impulsive electricians.

This paper is however on the transmission and application of hydraulic power to machine tools, and the system has fortunately survived the injury often done by that numerous class who, having once seen a hole dug, are then not only able to explain *how* it was done, but to show how it could be done better.

There were two causes some 25 or 30 years ago which assisted the introduction of the Hydraulic System for special classes of machine tools—1st the increasing size and scantling of all boilers, bridge and ship work, and 2nd the increased areas thereby covered by the works themselves. This was pointed out by the author in a letter to *Engineering*, in 1871. So long as hydraulic power is confined to work of a more or less reciprocating character (with the one exception of capstans), there is no other system comparable with it on the score of economy; but when we come to driving lathes or planers, spread over large areas, electrical power comes in on the ground of the convenient way in which it can be transmitted over great distances, and the suitability of its motors for rotary work. Always bearing in mind that their suitability for the work to be done is ascertained, it may be stated that for transmitting and applying power over great distances water and electricity have both their special advantages. Electric transmission, if more costly, is on the other hand very conveniently applied at different points; travelling cranes may be cited as one of the best applications.

So far as the relative economy of hydraulic power, shafts and belting, or electricity, are comparable, it is easier to compare shafting with electricity than either of these with hydraulic power. In the case of the former: given an equally economical and efficient prime mover, for all reasonable distances, it resolves itself into a question of the interest on cost of shafting only, or on that of dynamo, with its leads, motors and shafting. When the distances become greater we can then compare the relative cost and advantages of hydraulic and electrical transmission. In many cases even this comparison is not possible, for the operations to be performed by the hydraulic machines and those driven by electricity are in many cases essentially different. Many of the heaviest operations done by hydraulic

tools only occupy so short a time that a large reserve of power must be stored up to render them practicable. For reasons of cost this is not possible with electricity, but in the hydraulic system, perhaps the most important feature is the accumulator, and it constitutes the most important factor in its economical success. We may at once eliminate this feature in an electric system on account of its present great cost, and of course in transmitting power by shafting or ropes it is also impossible; and it can only be adopted to a limited extent in pneumatic transmission.

It is not necessary to an audience like this to describe the Hydraulic Accumulator, but as there may be some to whom the principle on which it acts is not familiar, the author would explain it popularly as follows :—

The water stored under pressure in an accumulator (which is nothing more than an ordinary hydraulic cylinder, the ram of which is loaded) possesses the same advantage for meeting the varying and sometimes large and sudden demands of a number of machine tools as a balance in the bank does, in enabling people to meet their financial engagements. As we all know, without a banking account, if a sudden and large demand comes upon us we would, if only in receipt of a weekly wage, probably have to ask for time to pay. But if we have a reserve accumulated at our bankers, we can give a cheque, and the painful operation is effected at once. In the case of transmission by shafting or electricity, the prime mover must be large enough to meet such cases when they occur, but in the hydraulic system, not only is the prime mover not required to be equal to the greatest efforts (only occasionally required), but on the other hand the size of the prime mover can be very much reduced; for the accumulator allows of the smaller engine being kept more or less continuously running and storing up

power during the very considerable intervals when only a portion of the machines are at work.

This question of the proportion of machines absolutely engaged "tooling" and those standing idle, while work is being taken to or from them, or from other causes is not a new one. The author alluded to this in a paper read by him in 1886, and gave some figures based on data published by Mr. Wilson Hartnell. It may not be amiss to draw attention to the very considerable mechanical, if only occasional, work done in Hydraulic Machine Tools with prime movers of almost pigmy proportions. In our youthful days the raising of the Conway Bridge Tubes was always cited as an instance of a great effort. Well the best they did was lifting 1,300 tons 13 feet in 60 minutes, or 282 foot tons per minute. The ordinary 150 tons Riveting Machine will make 4 strokes per minute, of 6in. each = 300 foot tons per minute, but the mechanical effort is really more, for these two feet are really done in little over 20 seconds, the remaining 40 seconds being required for the return stroke of the ram. If such a machine had to be driven by shafting or electricity, in the first place the prime mover must be equal to exerting this 300 tons in 20 seconds plus friction of shafting; and in the case of electric transmission the prime mover must be the same plus the losses incidental to the Dynamo, the cables and the electric motor and gearing between the prime mover and the machine. We will leave it to others to minimise or fix these losses, but we know that in the case of Pumps and Accumulator and Mains, which we may take as occupying the same place as the Dynamo, Leads, and Electric Motor, the losses are extremely small.

The efficiency of good Pumps is 78 %, that of the Accumulator 91 %, and the loss in properly designed mains is extremely small.

Coming now to the Machine Tools to be worked by the water thus transmitted. It is of course understood that generally

speaking we are only discussing this evening machines suitable for hydraulic pressure, either by reason of their being required to exert a great force during a short period, or to exert in addition more numerous efforts (such as punching, shearing, or riveting) at distances from the prime mover beyond the reach of shafting.

In the former case we have shown that the hydraulic system alone meets the case, and for great efforts, such as forging, flanging, &c., the same applies. But in smaller machines there is more room for divergent opinions. There is a great difference between an engineer and a mechanic. The mechanic may have twenty times the designing faculty, may be a perfect accumulator, full of formulæ, and be a technical Titian at the drawing board, but unless he has judgment, and knows when to stop in the application of any particular system, he is not an engineer in the broadest sense of the term.

This brings us to the consideration of the suitability of hydraulic pressure for punching and similar machinery, placed about large ship and bridge yards. We have lately seen some startling instances, from an electrical standpoint, of the wastefulness of this class of machine driven by separate steam engines, all of which was pointed out by the author 24 years ago, in many technical journals and papers, with the view of substituting hydraulic machines.

Electricity as a motive power for moderate sized machines, in frequent work certainly seems to fulfil most of the conditions, but it cannot claim to have all its own way. The machine has to wait till the speed of the motor is got up, and a similar loss of time and power ensues when the machine is being stopped, whereas in the hydraulic machine, it is only consuming power while work is being done. There are of course losses peculiar to the hydraulic system, and there are climatic considerations to be considered, and the final verdict as to the power selected

can only be the result of experience and judgment brought to bear on each particular case.

In many classes of work it is essential that the exact pressure exerted be known and that the same pressure be exerted every time it is applied under similar conditions. This is the case more especially in riveting. In the case of riveting, as is well known, the length of rivets when finally closed is more or less a varying one, owing to the temperature, number of thicknesses of plates, etc. The hydraulic ram can be made of sufficient stroke to do the shortest or the longest and at the end in every case exert the same final pressure. We have in this a very important advantage—only obtainable in hydraulic machines. This range of travel is one of the chief advantages of all hydraulic machines, and is practically unobtainable in geared machines, whether driven by shafting or electric motors.

Simplicity and fewness of parts should be the aim of the hydraulic engineer. Many apparently and ought-to-be satisfactory mechanical devices have been brought out to economise the water consumed, but the only really efficient one when suitable is that due to the use of an overhead tank and a simple non-return valve; or in some special cases the use of three rams. There is no doubt but that in the future, electricity will have to be considered as one of the factors in an economical works plant. In some cases it will supplant both shafting and hydraulic pressure, but there will always be applications left for the older systems. No really useful mechanical improvement is ever altogether lost. New inventions do not push out the old ones, but help to meet the constantly increasing demands for labour-saving appliances.

DISCUSSION.

The PRESIDENT (Mr. J. Nasmith) said there were several points which appeared to him to afford a line of argument, from which an interesting discussion might arise. One of these was the scope of hydraulically driven tools, and the second the limitation which must be placed upon the use of this power for the purpose of driving tools. It seemed to him that the great merit of the hydraulic system was the fact of the "balance at the bank,"—to use Mr. Tweddell's phrase—which was available to be drawn upon as required, in the reserve of power, which they could call upon at any moment. Another special feature was the enormous force behind the ram of a hydraulically-worked machine, which was due not only to the pressure of water, but to the force stored in the accumulator. Professor Unwin had shown that there was a very much larger power behind the ram than might at first appear likely. These considerations pointed to the conclusion that where they had heavy work to do, and that as quickly as possible—as for instance, in flanging up a boiler front, or in stamping, &c.—the hydraulic system appeared to "fill the bill," as by it they could obtain the means of applying a large force very quickly, and with the least possible loss. Of course, if they began to discuss the subject from a comparative point of view, and went into the matter of cost, they would never finish their discussion, but he suggested that they should ignore the question of cost in whatever remarks might be made, and deal with the matter from the point of view of merit alone. There were present, advocates of all kinds of systems for the distribution of power, but he thought it might be reasonably allowed that the claim made by Mr. Tweddell twenty years ago, that by the hydraulic system

an enormous power could be taken from a central station and transmitted over long distances, with only a small loss of power at the terminal point, and that it lent itself to power-distribution more economically than the then existing means, had been entirely substantiated. The claim now made on behalf of electric transmission of power was, therefore, only a resuscitation of that put forward by Mr. Tweddell twenty years ago with regard to the system with which he was connected.

Mr. W. J. Jenkins expressed his regret that the author had died before the paper was read. The paper, although short, suggested a good many points of view from which the subject could be regarded. One admirable point was that although the author was well-known as a staunch advocate of hydraulic transmission of power, he had admitted its limitations. With regard to electricity—which had been referred to by Mr. Tweddell—he thought it must be admitted that, independently of the question of cost, that method of distribution was one which possessed many conveniences that were not obtainable with any other method. For example, electrically driven machines could be placed in almost any position in a works, just where they were handiest, whereas with ordinary shafting it was often very difficult to arrange a machine in a position where it would not have its back to another, or be in the way of something else. There would no doubt be a great extension of electric driving when it was finally settled whether it was more or less economical than ordinary shafting. In some places it was undoubtedly more economical, but in others it was not so. The wide extension of the use of electricity for driving machine tools on the Continent, seemed to point to the fact that where coal was dear, electricity was better than shafting. With regard to the transmission of power, one drawback to the hydraulic system was the comparatively small power that could be transmitted

through a pipe of ordinary dimensions, and the limited dimensions of the pipes which could be used. In the Manchester Corporation Hydraulic installation the pipes were 6in. diam. and of considerable weight, but they would not convey more than 800 indicated HP per hour. A 6in. gas main, of less than half the weight of the hydraulic pipes, would transmit to a gas engine using 20 cubic feet per indicated HP per hour, over 800 HP. Of course a gas engine would not be suitable under many circumstances where hydraulic power was specially applicable. For lifts and that kind of work, hydraulic power was unequalled, but where anything like rotary motion was required it was quite out of court. Where the conditions of a case required a simple "push and pull" hydraulic power was all right, but for a revolving action it was not suitable. He had some information about the sizes of slide valves of hydraulic lifts, which would be interesting. The proper dimensioning of hydraulic slide valves was a subject that received very little attention in the technical literature of the country. Everyone knew that in a hydraulic installation, unless the design was made by very experienced men, the size of the valves was frequently a cause of failure. The valves were almost invariably much too large, some of them requiring a man using both hands to move them. The case in point was a simple hoist multiplying ten to one; the ram was 7¼in. diam., and the ports of the valve were 1in. by ⅛in. The lift was used to raise about half-a-ton, 60 odd feet, at a velocity of about 4ft. per second, which was the maximum velocity for lifting the full load. The slide valve was arranged to open a definite distance, and the corresponding velocity of the load was determined by actual measurement. When the valve was $\frac{1}{6}$ open, the speed of lift was obtained by multiplying the theoretical velocity of the flow of water through the orifice by 0·71; at $\frac{2}{6}$ open, by 0·61; $\frac{3}{6}$ open, by 0·54; $\frac{4}{6}$ open, by 0·48; $\frac{5}{6}$ open, by 0·44; and fully open, by

0·40, so that only three times more water came through when the valve was fully open than when it was $\frac{1}{8}$ open. For lowering the load the co-efficient was 0·51 for all degrees of opening, because the exhaust pipes emptied themselves faster than the water flowed out of the port orifice. In calculating the head to which the velocity of inflow or outflow was due, attention should be paid to the increased pressure in lifting, and decreased pressure in lowering due to the friction of the mechanism. The pressure in the valve chest and in the cylinder were taken by gauges during the trial here recorded. His experience had been that as a rule valves were made far too large and cumbersome. When at Messrs. Firth's works at Sheffield during a visit by the Association, he had been struck with the ease with which the valves of the large press were worked, and should like to know how it was done.

Mr. Tweddell had stated years ago that the pressure put upon a rivet depended more upon the distance the ram had to travel before it struck the rivet than upon the steady pressure of the accumulator, if the latter was a quick one of the differential type. Mr. Tweddell had previously shown that although the pressure in the mains given by the accumulator when the press was standing was 1,500lbs. per square inch, it was possible to get 2,400lbs. per square inch pressure on the ram in riveting, by means of the inertia of the accumulator when falling; and the author's statement, that the ram could exert exactly the same final pressure for the shortest or longest rivets was therefore strange—unless Mr. Tweddell had given up the differential accumulator. If the ram had to travel for riveting two thin plates, or two thin parts of a plate, through 3in. before the cup came against the rivet, the velocity acquired would be a certain amount; if the next rivet was put in a thicker place, so that the ram had only to travel say 1in. or 1½in., the inertia could not be so great because the fall would not be so large. Judging,

therefore, from the paper it seemed that the use of the differential accumulator had been given up, and if so, it would be interesting to know why ?

Mr. JAMES PLATT (of Messrs. Fielding and Platt, Gloucester) explained that the paper just read was only a rough draft found amongst Mr. Tweddell's papers after his death, and certainly had he lived, it would have been much more complete, and worthy of him.

He might say that he had first made Mr. Tweddell's acquaintance when the latter was a student at Cheltenham College. Mr. Tweddell afterwards served his time at Newcastle, and commenced business at Sunderland, and when Messrs. Thompson & Boyd, who had taken up the manufacture of his fixed riveter, refused to take up the portable one, Mr. Tweddell brought it to his (Mr. Platts') firm, who agreed to make it from the sketch supplied by Mr. Tweddell. At first they started with the idea that a portable riveter should be capable of being carried about by men, and began to make them on that principle.

In the first machine they had a very good gun-metal cylinder, and good forged steel arms, which stood their work, but in the general run of machines made they had a number of failures, and the weight gradually increased, as it was found that the idea of portability would be best neglected. In this respect it might not be inappropriate to mention that last week his firm sent out a portable riveter weighing 14 tons.

When they first commenced to make hydraulic riveters, they went in for more moderate pressures than were now common. The ordinary machines put 20 tons on the rivet; this was increased to 30 tons, which prevailed for a time. When Messrs. Beyer and Peacock determined to apply hydraulic riveting, they had a riveter made to give 40 tons, which was found to be too

much for the thickness of plates and size of rivets in those days, because the pressure of the rivets inside the rivet holes bulged the edge of the plates by increasing the size of the hole, and it was therefore reduced to 35 tons, which was the utmost the ⅛in. plate would stand. Messrs. Sharp, Stewart & Co., also ordered one of 40 tons, and they found that it was too large a pressure, and subsequently had it reduced. With the plate closing arrangement, however, a much larger maximum pressure could be used without injury to the plates, as the rivet was first closed by a less pressure before the total pressure was put on.

At first they had many objections to contend with in introducing their machines, one being the great waste of power, as the maximum pressure was only required for a small portion of the stroke, the other part being practically wasted; but with the free piston, introduced by Mr. Tweddell, it was claimed that they always got the same force, and the maximum was at the end of the stroke, as stated in the paper. That was a great point in hydraulic riveting.

With regard to Accumulators, when Mr. Tweddell first applied his hydraulic system, he had a pump and accumulator for each machine, the latter being of the differential class, and the ram being of small area; the load fell about 12 inches, causing an intensified pressure at the end of the stroke, as with 1,500 in the main it rose to over 2,000 in the cylinder. Where many machines were used with large accumulators there was not the same excessive impact as with small accumulators.

He was in a marine shop the other day where they were riveting 1¼in. plates with 1¾in. rivets by a 100 tons machine very successfully. In another shop a 120 tons riveter was being used on a boiler shell to work at 220lbs., with equally satisfactory results, so that it was evidently quite unnecessary to have the enormous pressures at one time adopted, which the plates would not stand without injury.

With regard to the comparative merits of the various systems of power transmission, undoubtedly hydraulic power was very suitable for a great many purposes, but there were other requirements which were far more efficiently met by electricity, or, in some cases, compressed air.

He might add that he always found Mr. Tweddell to be a perfect gentleman of most genial manners, who had the great faculty of getting people to adopt anything he recommended.

Mr. A. Gem said, mention was made in the paper of a hydraulic tool for expanding boiler tubes. He presumed it was a failure because the Dudgeon expander was now almost universally used.

Mr. James Platt, in reply, remarked that it was not altogether a success. It consisted of a mandril with two cones, and a hydraulic cylinder fixed on one cone, the ram pushed up the other, expanding dies being arranged to fit the cones and inside the tube. This arrangement was put into the tube and the pump put on, but although the tube was expanded, the tool did not prove a success, as the tube did not follow the inequalities of the hole in the tube plate. The design was ingenious, but the tool was not equal to the roller expander for efficiency.

With regard to valves and the power required to work them, referred to by Mr. Jenkins, they had applied to their Forging Presses a small supplementary valve which let the water into the chamber at each end of the larger valve, so that a boy could work the machine.

The proportion of the valve was a very important point and depended upon the purpose the machine was required to serve. Experience alone could enable them to determine this.

Mr. Gilbert Lewis said he was glad to see that Mr. Tweddell had given a share of praise to the manufacturers who had

assisted in carrying out his designs. As to the relative advantages of the different methods of distributing power, there was no doubt that for certain purposes where great power was required for reciprocating action, no other method could possibly be compared with the hydraulic system, but for rotary machines it was not applicable. Hydraulic power was very useful in riveting and similar machines. He did not agree with Mr. Jenkins's contention as to heavy valves. There were heavy hydraulic valves which could easily be opened with one hand because they had a balanced spindle to transmit the power from one side to another.

Mr. Lewis further observed that many engineers were always best known in connection with some special work or invention which was due to them, and he ventured to prophesy that just as they spoke of Nasmyth and his steam hammer, &c., so the name of Tweddell would go down to posterity in connection with the portable riveter, for posterity would not be true to itself if it did not recognize the old pioneers who had built up the grand edifice of mechanical science.

Mr. H. Webb remarked that the explanation previously given by Mr. Platt would no doubt mitigate the disappointment, which many of the members had experienced, that the paper did not go more fully into the principles of the application of hydraulic power to machines. He wished to state how much forgers of iron and steel were indebted to hydraulic engineers for the introduction of the hydraulic press for making forgings. Since the adoption of Bessemer steel for the heaviest shafting, guns, &c., it had become impossible to forge what was required in the hammer owing to the cost of foundations, &c., but the hydraulic press then came in with much better results than those obtained with the hammer, whilst one special point was that the inside of the shafting was affected equally with the

outside. It was a wonderful tool, and far less costly and more convenient than the steam hammer for large steel forgings.

The PRESIDENT observed that some years ago an injunction was obtained, by the trustees of a Catholic chapel, against Sir Joseph Whitworth for working a steam hammer and shaking down the figures in the chapel. Hydraulic presses had been previously introduced, but this action led to a great increase in their use, for Sir Joseph Whitworth was compelled to forge by hydraulic power in order not to damage the chapel. Hydraulic power had practically made one industry possible—*i.e.*, the cycle trade, in that it enabled seamless steel tubes to be drawn, and thus placed a material at the command of the cycle maker, without which that industry would never have attained its present position. In Birmingham he had seen a very remarkable method for making shells from which to draw solid copper tubes, consisting of a clamp which held a solid cylinder of copper, up to the centre of which was brought a tool with a pear-shaped nose which was pressed against the centre by hydraulic power, and was also given a rotary motion. As this tool revolved and was subjected to the hydraulic pressure it gradually made the metal flow round until a complete shell was formed with a hole down it, the loss of metal being only two ounces. The tubes were afterwards drawn from the shells thus formed.

In conclusion, he would propose a joint vote of thanks to Mr. Tweddell's executors for allowing them to read the paper; to Mr. Ashbury for his kindness in reading it; and to Mr. Platt—who, he hoped, would at some future date read a more exhaustive paper on the subject—for his attendance and interesting speech.

Mr. HENRY JOHNSON seconded the motion which was unanimously adopted.

Mr. T. Ashbury in responding observed that Mr. Tweddell himself had stated in a former paper* that Mr. Gledhill—who was one of their own members—of Sir J. Whitworth & Co., had the honour of having introduced the hydraulic forging press.

Mr. James Platt also responded and confirmed the above statement. He might also mention that his firm made hydraulic machines for bicycle tube drawing. Solid drawn steel tubes were replacing copper for pipes on steamships, owing to the high pressures now prevailing.

* Proceedings Institute Civil Engineers, Vol. cxvii.

WELDED STEEL MAINS AND JOINTS.

READ SATURDAY, 22ND FEBRUARY, 1896,

BY

MR. J. G. STEWART,

(GLASGOW.)

The last few years have been remarkable for the great development and extension of mining abroad, particularly in Australia and South Africa.

It frequently happens that deposits of great value occur in the most inaccessible places, and where there is an absence of water. These two conditions have made light steel pipes a necessity; and if necessity is the mother of invention, invention is the mother of supply, and engineers, in such cases, are now able to obtain at much lower cost than that of cast-iron pipes, feather-weight pipes, lap-welded, of mild steel, which there is nothing to show may not, when properly coated and with some attention, prove to be as durable. In the United States riveted steel pipes of very thin sheet have been extensively used for at least a quarter of a century, and I am informed that in California many of these riveted pipes are still in use after quite twenty years' service. In our own colonies we have provided lap-welded rolled pipes of open-hearth Siemens' mild steel, which can be laid in position very much faster and requiring no skilled labour, at much less expense than riveted pipes.

Steel pipes to withstand working pressures of 500ft. head have been supplied from 12in. in diameter, of thickness as small as No. 12 wire guage, weighing for a 12in. pipe no more than 39lbs. per yard, as compared with the weight of a 12in. light cast-iron pipe of 247lbs. per yard.

As the cost of carriage of these pipes, which were made for the Buluwayo Water Works, amounted to considerably more than the actual cost here, it will be evident that the total cost when delivered there was a mere fraction of the cost of cast-iron pipes.

It was also one of the necessities of transport that no individual pipe should weigh more than 200lbs. Had the pipes been made of cast-iron they would consequently have had to be made in lengths of 25in., or with eight times as many joints as the steel pipes.

They were made with a patent joint similar to the ordinary spigot and faucet joint of the cast-iron pipe, but made with so much less lead space as to reduce the quanity of lead required to one-third. They were sent out dipped in Smith's Solution, and they might have been re-coated at their destination, the mixture in the second tank being a very thick tar, put on at a considerably lower temperature, which has no tendency to remove the first coating.

25in. pipes have been made $\frac{3}{16}$in. thick. In this instance, the weight was 132lbs. per yard, as against 784lbs. for the lightest cast-iron pipe equivalent to one-sixth.

The carriage was £10 per ton, and the actual saving by using steel pipes was 73½ % of the estimated cost of cast-iron. In other words, the steel pipes cost little more that one quarter of the cast-iron.

Steel pipes may also become almost a necessity even in our own neighbourhood, in cases where pressure is very high. An instance of this kind occurs not far from here, where the Bradford Corporation are laying a very large quantity of 36in. diameter steel pipes, ½in. and $\frac{5}{8}$in. thick.

The largest quantity of steel pipes is turned out for the purpose of water supply, but perhaps the most important use of

steel pipes is for the transmission of high-pressure steam. When the great number of accidents which have occurred owing to burst steam pipes, and when the vibration and shocks to which a steam line is subjected are considered, it is surprising that mild steel pipes are not more generally used for this purpose. It may be, however, that the very rigorous duty which a steam pipe has to perform is the very reason why in this matter more conservatism and caution have been displayed. Slowly, however, engineers are giving more consideration to steel for steam pipes, and where they have been used I have not heard of any dissatisfaction with the result. The Admiralty are fitting steel steam pipes very largely, though they have not yet discarded the somewhat absurd arrangement of riveting a strap along and across the weld.

It would appear to be better to devote the money spent in fitting this butt strap, to making a very thorough test of each individual pipe. A very high hydraulic pressure, amounting to four or five times the working pressure, might be put upon the pipe, which at the same time might be subjected to percussive pressure got by hammering the pipe from end to end while the pressure is on. A circular strip might be cut from each end and tested by breaking, to ascertain that the welding had not damaged in any way the material. Such tests rigorously carried out would insure, on the whole, a more reliable pipe, and the material would not be weakened by drilling rivet holes, but the full section would be left everywhere. There would be no rivet holes to give possible trouble, and no rivet heads for the steam to cut. The pipe, being of symmetrical sections, would be better adapted to withstand strains due to expansion and bending. It could also be used as spigot of an expansion joint which the strap prevents.

The difficulty of keeping steam pipes free from condensed water and of providing properly for expansion, suggests that

the question of designing steam lines should receive more attention than is often given.

The arrangements made with the view of providing for expansion, are often such as to cause greater strains at some points than would probably have occurred if these arrangements had not existed.

Sliding expansions, which were very commonly fitted to cast-iron pipes, are seldom required with steel pipes, as it is often found that a steel pipe line with only a few bends has been far too flexible, and an unduly great vibration has been set up.

Sliding expansions have been fitted in case where one or both ends of the line were not rigidly secured, and owing to the flexibility of the steel pipe the expansion pipe moved out as far as the bolts would allow when the pressure came on. In another case, in which there were no bolts, the steam pressure broke the bolts which coupled the end of the pipe to the steam chest, and came out altogether, killing some men. In all cases where bends are fitted for expansion, including spirals, cork-screws, &c., these should and are generally made 20% heavier than the pipes.

Provisions for getting rid of condensed water are sometimes defective, as a part of the line has not been drained at all, insuring the existence in that part, when the stop valves are closed, of a column of water. As is well known, and can be shown by the water-hammer experiment, this water rushes to meet the steam, and may cause a break some distance from the place where it has collected. Another defective arrangement is to have the draining arrangements non-automatic, and depending upon the forethought or memory of an engine tender.

A steel suitable for welding, and capable of withstanding free heating, can be produced by the Siemens-Martin process, at little greater cost than the ordinary boiler plate. It can be

welded so as to show at the welded part an average strength and elasticity in no way inferior to the rest of the tube, or to the material before it was welded.

With reference to the tests of the steel out of which pipes are made, engineers would be well advised to test only strips cut from the finished pipes. Tests upon the steel plate out of which the pipe is to be made, afford no guarantee as to the quality or state of the metal when it is formed into welded tubes. Steel plates of the best quality may be made into pipes of the most inferior description. It is necessary to remember that there is a great difference between the possiblities of injuring the material in tube making and boiler making. As a consequence, the tests must all be repeated upon the pipe, which makes the first series of tests upon the steel plates unnecessary. The tests which the steel pipe ought to satisfy are an ultimate tensile stress of from 21 to 26 tons, and an elongation of 20%. This is upon steel pipes of fair thickness; when less than $\frac{1}{4}$in. thick the strength will be about a ton greater. There are, however, other qualifications than these tests, or the steel which has passed these tests may be wanting in other ways. They partly depend upon the steel maker, and partly upon the treatment of the steel in making the pipe, and as it is almost impossible for inspection of any kind to detect the want of, or after, to alter these qualities, that can only be left to the character and experience of the manufacturer.

It is to be regretted that there is no standard criterion for tubes either as to quality of material or exactness of dimensions. If any such requirements are put into a specification they are generally vague, viz., the material is to be good mild steel; the tubes are to be round, straight, of even thickness and exact diameter, free from surface defects; the gauges for the screwed ends are to be an easy fit, but not too slack. All somewhat too much of the size of a lump of chalk.

The admiralty specification is clear, namely: the material cut from the tubes must have an ultimate tensile strength not exceeding 26 tons and not less than 20, with an elongation before fracture of 27% upon a three-inch length. There are various mechanical tests which the tubes must stand, but none of which are so severe as the tensile tests, and are not quoted here. Pieces of tube 2in. long must be capable of being hammered on end until their length is reduced to 1¼in. without fracture. The weight of each tube must be within 5% over and 2½% below the specified weight. The diameter must not be less than that specified, nor more than 1% over that size. If 10% of the tubes should fail on examination to satisfy these requirements, or to withstand a pressure of 1,000lbs., the whole order is to be rejected,

Another condition may be quoted which must surely be an heirloom handed down from the earliest days of boiler-tube making in Birmingham: "Welded tubes are not to be brazed to cover defective welding." Upon this specification all manufacturers are placed on terms of equality, and the conditions are not too rigorous to exclude a fair commercial article.

It would be very much to the advantage of the manufacturer and the user if some such standard were generally understood to apply to all tubes. It is to be understood that in these remarks the word tube is applied particularly to hollow cylinders of under 6in. diameter; above that size, the nomenclature changes and they are called pipes.

A boiler tube is designated by its outer diameter; a pipe by its inner. At the same time, gas tubes of small sizes are commonly measured by the internal diameter.

If it is desired to test by breaking pieces of every individual pipe, this can easily be done by cutting a strip from each end of every pipe, and breaking it across the weld for elongation and

ultimate strength. In most cases, it is not the practice to test in this manner more than one in ten of the pipes to be used, by which means a fair idea may be got of the quality of the material and of the workmanship.

There is nothing to prevent a high hydraulic pressure test being employed upon every individual pipe; while this is done, the pipe should be subjected to percussive stress by heavy hammering upon the welded part from end to end.

Another condition of durability in a steam pipe may be said to be its resistance to corrosion. The question of corrosion in iron pipes has not been at all the difficulty which was at first freely predicted, and, even by the strongest advocates for steel pipes, considerably dreaded. A great many instances could be quoted of iron pipes in steam vessels, which have been in constant use for some years, and which have given no trouble whatever as to corrosion, external and internal, nor has there been any trouble whatever from scale from the pipes passing into the cylinders. But one case of iron steam pipes withstanding corrosion is worthy of quoting. The steam pipes of the "Great Eastern" were of iron, and riveted; when this steamer was broken up, I had the opportunity of seeing some pieces of the steam pipes. Although these pipes had been subjected to the most varied treatment, and had been for years neglected and exposed to damp, there was not the slightest sign of corrosion of any kind in any of the pipes which were subject to examination.

It was at one time proposed to use iron pipes with an internal copper deposited coating, in order to protect the iron against the supposed effects of corrosion; when, however, it was found that corrosion was not the trouble which had been anticipated, the copper was promptly discarded, as the possibilities of the copper surface being broken, and causing undue pitting at that point, were considered to be greater than the

doubtful advantage of the copper as a safeguard against corrosion.

It may be stated here that though the title of these remarks is "Welded Steel Mains and Joints," this is not the reason why nothing has been stated with regard to iron pipes. Large pipes made of Siemens-Martin open hearth steel, which is the material I designate by the word steel, are so infinitely superior in uniformity of quality, ductility, and, I believe, dependability, to pipes made of puddled iron, that I have not thought it advisable to mention these latter at all. While in testing large pipes of steel the results are generally fairly uniform, so much so, as to make almost certain that any required test can be predicted beforehand; it is somewhat difficult to obtain as uniform results from pipes made from iron plates. I have been told that steel is not trustworthy; that it is imbued with a spirit of deception. The old-fashioned geologists used to preach that fossils were the creation of deceptive spirits lodged in the rocks to mislead the inquiring mind. It may be so with steel. It may put on the guise of uniformity, temperateness, and long-suffering to worm itself into confidence, and then to give way all at once; but, until I personally find some instance of this sort I shall continue to believe that it is the best material for making large pipes from. It is not meant at the same time to depreciate the value of wrought iron as a material for boiler tubes.

The ultimate strength of a steel weld by the process of rolling tubes is amongst fair but ordinary samples, from 26 tons maximum to 22 tons minimum. The list given on opposite page shows the result of breaking some sample pieces recently. No piece which was tested has been omitted, and they were all ordinary samples. It will be noticed that the thicker pieces give the best results. The ultimate strength of an iron weld taken in the same way should not be estimated to be more than 15 tons.

No.	Dimensions of Piece.			Permanent Deforming Stress per sq. inch.	Breaking Stress per sq. inch.	Elongation % on 8in.
	Breadth.	Thickness.	Area.			
1	1·46	·14	·19	14·8	25·8	17½
2	1·47	·14	·192	15·1	25·1	19
3	1·49	·27	·402	15·6	22	22½
4	1·49	·24	·358	16·5	24·7	23½
5	1·49	·31	·462	15·8	21·7	35
6	1·48	·33	·488	16·6	24	30½
7	1·48	·32	·474	16·1	24·7	29
8	1·51	·34	·514	15·5	24·5	31
9	1·49	·33	·491	15·7	24·7	32½
10	1·5	·365	·547	15·8	24·3	33
11	1·5	·32	·48	16	24·3	23
12	1·49	·36	·536	15·9	25	30

Steel pipes formed out of the solid would appear on the face of it to offer the best possible pipe for withstanding pressures, but up to the present time the difficulties of making large pipes without welding can hardly be said to have been overcome. Recently, small tubes have been made after a great deal of expense and experimenting with different systems of manufacture, with some degree of success; but I have not been able to learn from any persons who have used them that they are more reliable or of better quality than welded tubes. All my experience of weldless tubes, so far as practically manufactnred up to this time, is that they are less reliable and have no real advantage. I do not mean to be understood to say that no progress has been made in the manufacture of weldless tubes, but such progress as has been made, is not sufficient to enable anyone to say that the methods of manufacture insure reliability of these tubes greater or even as great as welded tubes. The fact that scarcely any firm of tube makers make these tubes, although the process of manufacture is well known, would appear to show that they at least have no faith in any superiority of these tubes over the welded tube.

Again, the cost of even these small sizes has not yet been reduced to such an extent as to enable them to be used for most of the ordinary purposes for which welded tubes are in use.

At the same time, the quality of the welded steel pipes has improved very much, and as a consequence there would not appear to be inducement in any advantage of the weldless steel pipe to cause the users to pay the very much greater price, which, even if they could be manufactured satisfactorily, would appear from the processes which have been developed up to the present to be required.

The form of joint to be used for connecting steel pipes together depends upon whether the joint is to be permanent or temporary, and also upon the pressure and the nature of the stresses to which the joint is to be subjected. If the stress to be borne is simply pressure, tending to blow the pipes apart, the designing of the joint is comparatively simplified; but generally there is a bending action, due to the pipes not being supported continuously along the line, to unequal temperature of parts of the pipe, and to shocks and vibration. These latter conditions prevail more or less in all cases of steam pipes. A light and simple form of flange joint suitable for the most moderate pressure is made by bulging and turning over the end of the pipe to form the flange, Fig. 1. It is of course apparent that the metal of the pipe is much too thin to form a proper flange, unless thickened up very considerably before or after being turned over, as it forms an unstayed thin surface between the bolts. A flat ring has been put behind for the purpose of helping this thin flange, but a better form of joint may be made by fitting a ring of stamped angle steel behind the turned over flange which makes the joint much stronger, Fig. 2. It has however, the disadvantage of having nothing to hold in the jointing material, which in the course of time, owing to cooling and heating probably creeps a little, and is soon afterwards blown out. To obviate this, the cast steel flange has been made similar to the stamped steel, but with a bored out recess in the face of one of the flanges which holds the two

small turned-over flanges and the jointing material in. The jointing material is thus securely held in, Fig. 8.

This type of flange can also be made in two parts, which are cast with projections and recesses dovetailing together when fixed in position, and when bolted up hold as securely as if the flanges were solid. The principal advantage of this arrangement is to enable the flanges to be shipped separately from the pipes. The slight recess formed at the place where the small flanges meet forms a lodging place for water in the lower part of the pipe, and although a very small amount can possibly collect here, I believe it may have some effect on destroying the jointing material. It is sometimes an advantage, or a necessity to have the flange firmly fixed to the pipe; riveting on of flanges is however not regarded generally as suitable for steam pipes, as the rivets are liable to leak and the steam has the effect of cutting away the head, Fig. 4. A flange of steel, screwed very hard on to the pipe, and with a properly formed vanishing thread so as to weaken only by the smallest appreciable extent the strength of the pipe, and riveted slightly over on the outside face of the flange, forms a very good joint for a steam pipe, and the one which has been used probably most of all. In this case also a proper recess is made on one of the flanges, which holds the jointing material, and into which a part of the neighbouring flange just enters. This joint when properly made is capable of bearing extreme pressure, and like all other joints it should be proportioned so as to be considerably stronger than the pipes, Fig. 5.

A considerable number of experiments and tests have been made with flanges so screwed on with the result that it was found that the tube was burst before the flange moved, in fact in none of these tests have these flanges ever failed in any way. The same type of flange for reasons of economy has often been made of cast steel.

The type of flange which is preferred for highest pressures and durability is a steel or iron flange welded on to the end of the pipe, Fig. 6, Plate 3. This type of flange has practically no real advantage over that previously described, under ordinary circumstances of pressure, but it has a certain popularity owing to its being solidly welded to the pipe. Various experiments have been made in attempting to pull this flange off the pipe by hydraulic pressure, but as might have been expected the pipes have burst before the flanges were moved. This, however, is also the case with regard to attempts to remove the screwed on flange. For example :—

A flange of steel screwed on to a pipe 9¼in. in diameter was tested up to a pressure of 2,400lbs. At this point the tube burst. The pressure on this flange was 70 tons, or 2½ tons per inch of screwed surface.

A 12in. × $\frac{7}{16}$in. tube, with flange screwed on, burst at a pressure of about 3,000lbs. The pressure sustained by this flange was 144 tons, or 9,000lbs. per inch of screwed surface.

The solid welded-on flange has also been experimented upon to a considerable extent, and all efforts to pull this, the flange from the pipe by internal pressure have failed.

In speaking of the thin flange formed out of the pipe, Fig. 1, I spoke of its being possible or desirable to thicken up this flange to the necessary thickness of an ordinary strong joint. This has been done, but not with large pipes. The cost of making such a flange upon a large pipe would be very great, as it would probably be found necessary, in order to get the full strength and provide a recess for jointing, to make the flange five times as thick as the tube. In whatever way this was done, it would require very great pressure or a very long time, and make the cost of such a joint for a large tube prohibitive.

Another form of joint which, although used sometimes for temporary purposes, is more generally permanent, is the connecting together of pipes by screwed sockets, and of screwing the pipes themselves after forming into spigot and faucet joints together. These have been made for sizes up to 86in., but the labour involved in putting together those large pipes by this kind of joint makes it difficult to see how it can be advantageously used as a removable joint. It is used very commonly for boring purposes.

Amongst permanent joints, or such as are generally used as permanent joints, there is the collar joint for water mains, formed by a rolled and welded steel collar, enclosing a certain length of the ends of the two pipes to be joined, with a space between the collar and the pipe, which is filled with lead, Fig. 7. The patent inserted lead joint, formed by bulging one end of the pipe so as to hold the other, or spigot end of the neighbouring pipe, and providing that the inside of this annular space is larger than the mouth, thereby forming a lock-joint (which prevents the lead from being blown out), is an improvement upon this; it consists of only one joint, while the first considered consists of two, and it is very generally used for water pipes, as the joint can be formed very rapidly. It also provides a certain amount of elasticity, and allows for expansion and movement of the pipe, without almost any leakage; and the leakage, if it does occur, is very easily taken up. The amount of lead required is very small, Fig. 8.

The only other form of jointing in use for a permanent purpose is that of riveting the pipes together, either by making them conical or telescopic. As this necessitates more work being done, and more time lost at the site where the pipes are laid (often in countries where labour for such a purpose can hardly be got), it seems as a general rule not to be so well suited as the two former joints described. Riveted-on steel

flanges, with inside riveting flush so as to offer no resistance to water flow, have also been used, but more commonly for vertical pipes, such as mining mains, Fig. 9 and Fig. 4.

Generally speaking, for hydraulic pressure the welded-on or the specially screwed on flanges are alone suitable, Fig. 6 and Fig. 5. For steam these flanges, with the addition of the steel flanges containing the flanges formed from the tube, as in Fig. 3. For water, where the pipes may have to be removed, the steel flanges and the stamped rings, or the cast steel flange riveted on, are generally used, as indicated in Figs. 2, 9, 5 and 4.

For permanent purposes the lead joint with the socket pressed from the solid pipe is the most suitable, Fig. 8.

DISCUSSION.

Mr. JAS. E. KELSALL asked the author's opinion as to what was a good steel for welding and for the manufacture of welded steel tubes, and especially with regard to the carbon and the manganese. The tests made by the author were certainly remarkably low, but he supposed they were taken entirely from steel pipes, and not previously from the steel manufactured for the purpose of making the pipes. This was undoubtedly, as stated by the author, the best course, and it rendered unnecessary the testing of the plates from which the tubes were made, as it gave very different results. Mr. Stewart had referred to the pipes of the Great Eastern as being of iron and riveted, and which had not undergone corrosion. This gave rise to a desire on his part for some further information on the question of iron *versus* steel for pipes, especially as he had by him a paper recently published in *Iron and Steel*, in which it was stated that the cutting of threads could

not be done so well on steel as on iron, and therefore the former was not so satisfactory for certain purposes. Mr. Kelsall also read further extracts from the above paper, and said he was surprised to find the poor opinion the author expressed with regard to steel pipes. In several cases, according to the paper, manufacturers had replaced iron pipes with steel ones, and watched very closely the results. The iron pipes, when taken out were still in good condition after six years use, but the steel pipes, after nine months trial had to be replaced by iron pipes, corrosion having rendered them useless.

He would like to have Mr. Stewart's opinion on this question, if he had had any experience in the above direction. Certainly, he himself had been very much surprised to hear such a poor report with regard to the use of steel for tubes as was contained in the paper from which he had read extracts. It was a surprise to him that Mr. Stewart had not met with better results from solid drawn tubes, they having had excellent work in hydraulic tubes; of course tubes only were referred to, not pipes, pipes being entirely another thing, and could only be made from suitable plates rolled for that purpose. He quite agreed with the author that welding, properly carried out, was far superior to riveting.

Mr. Alfred Saxon observed that the author had said nothing about the cost of the various processes. For the information of the members, he might mention that he had been looking at a quotation received from the author's firm, and found from it that the difference in cost between iron and steel tubes was, roughly speaking, about 10 per cent., at any rate, for the sizes specified in the estimate; whilst the difference between the welded and screwed flanges was also about 10 per cent. This was a matter of moment to engineers who had to use iron or steel pipes, and who had to decide between welded or screwed-on

flanges. Certainly, if they could get an article 10 per cent. cheaper than another, and which would, according to Mr. Stewart's statement, stand the tests equally as well, it was an advantage to them to use it.

Another question which engineers had to consider was the length of time in which the steel or iron pipes could be obtained. They were practically unobtainable for urgent or breakdown work, either because there were not sufficient iron and steel pipe manufacturers to meet the demand, or else because they did not care to do the work in a hurry. Where there was plenty of time in hand, it was quite desirable for high-pressure steam requirements, to adopt wrought iron or steel pipes as the case might be. Mr. Stewart had referred to the specifications which his firm received from engineers, or from people who had engineering work in hand. He might say that these were not always produced from the guiding hand of the engineers themselves, who frequently quoted from the instructions of the consulting engineer, who laid stress upon particular items which had to be quoted in the specifications. It seemed to him that there was a very wide field for the use of wrought iron or steel pipes in connection with the gas and water mains of the country, for, in many cases, like that of the Manchester Corporation, cast-iron pipes such as were used twenty years ago were still being laid down. Considering the cheapness, lightness, and advantages as regards carriage, our Corporations ought to avail themselves of these safer tubes and pipes. On page 56 the author said, "in another case, in which there were no bolts, the steam pressure broke the bolts, &c." This seemed rather self-contradictory. With regard to the methods of testing, these were no doubt very good, and the author had given very excellent advice for them to follow. He had, however, not touched upon the form of welding adopted at his own works, or any other particular method. He (Mr. Saxon) would

like to know what the author thought of electric welding for pipes, and would like him also to state how they welded the flanges and pipes together at his own works.

Mr. J. W. HEPWORTH asked the author's opinion as to the pickling of the steel plates and tubes as lately adopted by the Admiralty. Further, respecting the question of cutting a piece off the end of the pipe after welding, he would like to know what guarantee there was that the weld was as sound in the centre of the pipe, even supposing the piece tested was satisfactory. The author had referred to the strap over the weld, and it would be interesting to learn if he agreed with the advisability of putting this on in the case of pipes 7in. bore and upwards, and for steam working pressure of 150lbs. and upwards. He had great pleasure in expressing his appreciation of the author's able paper.

Mr. O. M. Row said the author had mentioned the carelessness that existed as to the method of getting rid of condensed water in steam pipes on the part of the men in charge. The automatic getting rid of condensation was certainly a point that might well be attended to. Mr. Stewart had also referred to the clearness of the Admiralty regulations. This was a very important matter. Many people who had their own ideas were afraid of expressing them distinctly, and consequently their specifications were vague, the result being that the contractor suffered, and not the consulting engineer, who was really to blame. The distinctness of the Admiralty regulations was certainly a good point, and very different were they in this respect from those furnished by many engineers. As to the corrosion of steel, that certainly appeared to him to be one of its faults. Mr. Stewart had referred to the pipes of the s.s. "Great Eastern," and the good condition in which they were found, but these pipes would probably be of iron, it being

before the introduction of steel for the purpose, and everyone knew that sailing and steam ships built of steel corroded more rapidly than the old-fashioned iron-built ships. He should like to know if there was any practical form of making odd sizes of cylindrical vessels of wrought iron or steel at a marketable price instead of cast iron, and were there any simple means of putting on branches for apparatus such as condensers and heaters of various kinds so as to avoid excessive weight and pattern-making. With regard to solid drawn tubes, he did not think that bicycle makers would continue to use them on account of their lightness and strength if they were faulty in any way. He had had considerable experience in indenting solid drawn steel tubes in a manner that a seamed tube would not stand, and he might add that a South Wales firm had received a very large order for solid drawn tubes for telegraph poles.

Mr. Henry Webb said that, although an iron maker, he agreed with the author that steel was the right material for pipes. He might give them a chapter out of his own experience with regard to steel-welded pipes in a boiler range at 200lb. pressure. They put a range up of 70ft. length, and the bore was 8in. diameter, with flanges screwed on. They had not been at work for many days before they began to spit at the flanges; the flanges were too thin and had not enough bolts in, and the contraction and expansion no doubt helped to make them leak. These were replaced by riveted flanges, he and she, that was, steel castings riveted on to the steel-welded pipe; these were turned up in the lathe before being riveted on, but they did not prove a good fit, and began to leak at the rivet holes. Then a third range was tried, it being insisted that the flanges should be strong, double riveted on to the pipe, and then each pipe turned in the lathe after the flanges were riveted on. Since then no trouble had been experienced.

Mr. W. Dronsfield asked what was the most suitable material, &c., for sprinkler pipes, where little or no circulation was required in most cases, but where a considerable pressure had to be withstood.

Mr. T. Settle said he would like to know the author's method of dealing with elbows, tee-branches, &c., on pipes; in pipes for engineer's use, from 6 to 12in. diameter, they often put cast-iron or steel elbows in. Was there any difficulty in making these elbows, either as regards expense or in other directions?

Mr. Geo. Saxon observed that what Mr. Webb had said simply meant that he had tried the riveted flanges and the screwed flanges, but he (Mr. Saxon) would like to emphasize Mr. Stewart's statement that the solid welded flanges were quite able to stand a very high test, and would, he had no doubt, have successfully stood the 200lb. pressure mentioned by Mr. Webb. He knew of cases where they were at the present time satisfactorily standing 160lb. pressure with no sign of giving way at all, and he should like Mr. Stewart to give them some information as to his experience with the welded flanges in cases of very high pressure.

Mr. Henry Bates said he did not see why the screwed flange should not be as good as the welded. The Belleville boilers were always fitted with screwed flanges. It was true there was some difficulty in connection with them, but this had been got over by having them turned first, which obviated the inconvenience of a rough thread caused by the roughness of the pipe.

Mr. A. G. Brown said the chief reason for the unsatisfactory working of screwed flanges was the fact of insufficient care being

devoted to their preparation. To be satisfactory they must be a "good job." He had been accustomed in America to use screwed joints on wrought-iron pipes exclusively, and usually they were coupled by a sleeve joint. It was seldom that they used, in long lengths, more than one pair of flanges, these having a taper thread, with a little increase of pitch in the die over the tap, and they never had any trouble with them. He had seen many miles of length of pipe, conveying natural gas, where cast-iron could not possibly be used owing to the leakage through the pores of the metal. These pipes were made of lap-welded iron, about $\frac{3}{8}$in. thick and 24, 30, and 36in. diameter, to carry 200 to 400lb. pressure; and in some cases, even 600lb. pressure had been put on per square inch, while in the pipes in the wells which were ordinary 6in. pipes, about $\frac{5}{16}$in. thick, 1000lb. pressure was not uncommon, without any, or practically any, leakage throughout the pipe. This could not be done without extremely good work in preparation and in making the joints, upon which the success or non-success of the pipes and screwed joints depended.

Mr. T. Settle commented upon the author's statement that a weld could be made with equal strength and elasticity to the rest of the tube, or to the material before welding. Did Mr. Stewart mean to say that the weld would really be as strong as the ordinary run of the pipe?

The President (Mr. J. Nasmith) observed that in copper steam pipes, especially for marine work, there had been frequent explosions, and as steam pressures had risen the making of a satisfactory brazed seam in large copper pipes had become a matter of more importance. In braze they got—what they did not get so largely in a weld—a considerable change in the molecular construction of the metal at that

particular point, and it was therefore difficult to obtain a satisfactory result.

The question of corrosion was an important one with respect to steel, and whether that difficulty could be overcome only experience could prove. Certainly, steel pipes and plates did corrode more rapidly than iron under some conditions. One thing that had prevented the wider adoption of steel sleepers for railways, was the fact that doubt existed as to whether they would not corrode so rapidly as to become more costly than the wooden sleepers. With regard to continuous draining, there was no doubt it was a matter of moment, and he thought that in designing long ranges of steam pipes engineers should take care to provide some means of automatic drainage, so that the water was always removed. As to the test strips taken out of the pipe, with regard to which a question had been asked, they could give no guarantee that the weld would be as sound in the middle, but if the strips were taken out and tested across the weld, and a fair number of pipes were taken, they might reasonably presume that the weld would be the same in the centre. Of course a weld had the fatal defect that if the surfaces were not properly cleaned they might get a defect on any part of the weld, but this was quite as possible in the end as in the middle, so that when the end was tested they might presume that the weld would be the same throughout. In testing they should deal with a sufficient number of pipes, take pains over the matter, and spend enough money on it, so that the soundness of the well should be thoroughly tested as suggested in the paper. If a high hydraulic pressure were applied to the pipe, whilst this was being treated percussively along the weld, so that along with the hydraulic pressure the material was subjected to vibration along what was considered the weak point, this test would absolutely demonstrate whether the weld was a good one or not. With regard to Mr. Webb's

experience, of course they did not know the circumstances; the pipes might not have been thick enough, or the flanges might have been poorly made, and so caused the result referred to.

As to welded and solid drawn pipes, the solid drawn steel tubes were of enormous value, especially for bicycles. Of course, for this purpose, the sizes were small, and if they wished to draw 10 or 12in, tubes out of a seamless ingot the power required would be enormous and the cost prohibitive, so that they must deal with the next best substitute. Tests had proved over and over again that if a weld were properly made there was substantially no diminution in the tensile strength of the material at the point where the weld took place. The matter thus resolved itself into a question of cost. If solid drawn tubes, properly made, could be obtained at the same price as lap-welded tubes, then, no doubt, something might be said to recommend them. This, however, was impossible in practice, and since they could obtain welded tubes practically as good, they were bound to fall back upon the latter.

Sprinkler pipes were, of course, those in which water was kept practically stationary for months together, and in which corrosion was not at all likely, as scarcely any oxidation was possible, but they were mostly of such small size as hardly to come within the scope of Mr. Stewart's paper.

He would conclude by moving a hearty vote of thanks to Mr. Stewart for his most interesting and instructive paper.

Mr. T. Daniels, in seconding the motion, observed that if a good thread were put on a pipe and also on the flange, he did not think any difficulty would be experienced in getting a good screwed pipe and joint.

Mr. Henry Bates mentioned that during a number of tests of steel plates, which he witnessed, at a large works, in no one case did they give way at the weld.

Mr. HENRY WEBB referred the members to the transactions of the Iron and Steel Institute for particulars of chemical, mechanical, and microscopical tests of the corrosion of steel and iron in sea, pure, and other water.

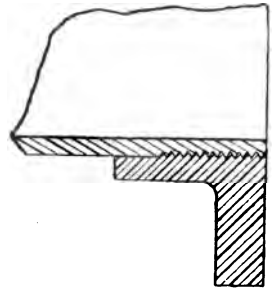
The vote of thanks was then put to the meeting, and carried with acclamation.

Mr. SAMUEL BOSWELL, in a communication, regretted his inability to be present during the reading of such an interesting paper, particularly when he considered the great loss of life, both ashore and afloat, accruing from the adoption of copper and cast-iron pipes. It was pleasing to hear that the Admiralty were now largely adopting steel mains where copper had recently proved so treacherous. He could not agree with the author that the butt-strap was an absurd arrangement. Certainly, he admitted that if they could rely on a long weld as being perfect it did seem a little antiquated, but could any pipe-maker guarantee that out of 50 pipes made from five different brands, and welded by five different men, 49 would be sound? If only one in 50 were defective (without being dangerously defective) the application of the butt-strap was worth the cost, because, if not perfectly welded throughout, the straining due to rolling in a heavy sea would find the weak spot. It might simply open the weld one half-inch, but even then it would be impossible to make it good by calking. The pipes could of course be tested to a high-pressure, but they were then in a state of rest being subject to a tensile strain, and even the hammering would not put them under such conditions as experienced when at work either ashore or afloat.

He was not in favour of the hammering while the pipes were under test, as personal damage, from his own experience, easily accrued from a jet of water suddenly escaping from a defective riveted or welded seam.

He had tested many strips cut from a welded pipe, but unfortunately they could not obtain their test strip from the most difficult part of the weld. If, to dispense with the sliding expansive joint of a cast-iron pipe were its only object, the steel pipe would be introduced with a good purpose, but when they considered the water hammer action in an inefficiently drained and badly made cast-iron pipe and the frequent loss of life thereby, it was astonishing how many cast-iron, and so few steel pipes were adopted. It was at any rate satisfactory to note that the former were a diminishing quantity and the latter the reverse. Of course, it was a special trade, and carried on by specialists, who employ men thoroughly trained to pipe-welding, and with such firms the customer was quite safe, as also the pipes turned out. On the contrary, there were many who rank little above a country blacksmith, and who imagined they could weld and make a steel pipe, hence the strict supervision insisted upon.

Of the joints for high-pressure pipes, up to say 8in. diameter, he considered No. 5 the best. Even that could be improved upon by turning the pipe perfectly round for a distance of about 1in. beyond the thread, and boring out the flange to slide over this portion according to sketch.



If needed, the edge of this flange could be calked, and the weakening of pipe due to screwing was practically overcome.

The first screwed-on flanges for high-pressure that came under his notice were made by a Bolton firm of boiler-makers twenty years ago. They were unsuccessful on account of not being deep enough, being simply flat 1⅛in. flanges. For jointing purposes, he preferred them turned quite flat, with a rough cut, and the joint made by means of a thin layer of cement, or thin asbestos ring; the thinner this was and the better, as there was so much less to perish and not so likely to blow out when it had perished. He could only, in conclusion, express his appreciation of the author's paper.

Mr. STEWART, at the meeting, cursorily replied to the points referred to in the discussion, and subsequently communicated the following detailed reply:—

In reply to the discussion, and to the various questions which have been raised by the reading of this paper, I will reply to them in the order in which they were asked:—The carbon in steel suitable for welding should not be higher than ·15%. I do not know that it is necessary to fix any minimum limit for the carbon when the steel has been made by the Siemen's process. Bessemer steel, when very low in carbon, is generally unsuitable, but this may not be due to the want of carbon, but to attendant results which accompany the entire elimination of the carbon. I cannot say very much of Bessemer steel, as I do not think that it is generally as uniform in quality as Siemen's steel, nor as well suited for making pipes. The manganese present should be ·50%, the ultimate tensile strength about 24 tons, and the elongation at least 20% upon 8in. The tests given in the paper were all taken upon pieces cut from finished tubes, and containing the weld transversely, or across the specimen. With respect to the extracts read by Mr. Kelsall from an American paper, I can only say that the opinion there expressed may be well founded, but I am confident that, if so,

the steel dealt with is a very different material from that which I have spoken of. It is probably Bessemer iron, which is largely used for making pipes in America, being cheaper than puddled iron. My remarks were entirely confined to pipes made from Siemen's-Martin steel of a special purity, which costs considerably more per ton than puddled iron.

The reason why a difficulty has been found in getting one or two steel pipes of large size quickly, particularly if some special work has to be done upon them, is not because of the manufacturer being too busy, but owing to its being a necessity of manufacture to make a considerable quantity of pipes of one size at a time. Owing to there being many differences of opinion amongst engineers as to the proper thicknesses of pipes and kinds of joints, it is not expedient for the manufacturer to carry a stock.

With reference to electric welding, to which I did not allude, I may say that for some special purposes it has been successfully used, such as for welding, or, it might be more properly described as fusing together branch pipes, in cases in which it would be almost impossible to apply gas heat to the joints. It is better to avoid, if possible, forms which can not be easily welded by fuel, as the electric heating entails more risk of injuring the material, and the weld is consequently less dependable.

The pipes and flanges are welded together by first shrinking the flange on the pipe, and by afterwards heating both to the welding temperature, and expanding the end of the pipe against the flange, exerting sufficient pressure to weld the two surfaces firmly together.

I am of opinion that pickling of both plates and tubes, as adopted by the Admiralty, detects surface defects which might otherwise remain unnoticed, and is consequently a commendable practice.

I do not think that there is any test of a pipe so good as that of submitting every one to a high hydraulic pressure, but some engineers do not consider that sufficient, as the result is somewhat negative. They desire to know the absolute strength of the pipe, and the elongation and the elastic limit. This information can be got fairly by testing strips, cut from the end, at comparatively small expense.

There is, of course, no guarantee that the weld in the centre of the pipe, or even two inches away from the strip tested, is in the same state of soundness. To ascertain this, we should require to test the whole length of the pipe by breaking, but when it was ascertained to be all good there would be no pipe left. It is common practice, however, to judge of the quality of all materials by sampling.

From an examination of the paper, it will be evident that I do not see the advantage of applying a butt strap to a pipe if it is properly welded, and suggested that a small part of the money spent on the butt strap might be better used in testing the pipe very thoroughly to say six times the working pressure.

With regard to corrosion, I was not aware that there was such a distinctive difference in corrosion in iron and steel ships. If such is the case, it does not appear to seriously affect the minds of ship-owners, who build steel vessels now almost universally. Cylindrical vessels of steel are now largely used in place of cast-iron, even for such commonplace articles as kegs for holding nails, which are made of welded steel completely, and branches of every kind are welded on to steel pipes and vessels, but the cost will vary greatly according to the forms required.

Bicycles are largely made of solid drawn tubes, and for such structural purposes they afford the minimum of weight for the maximum of strength and stiffness. I see no objection either to their use for such a purpose as telegraph poles, but I know

that, in many cases, they have had to be rejected in the most wholesale fashion when intended for boiler tubes, and that in some cases, after various fruitless attempts to get weldless tubes of the required quality, engineers have had to accept welded tubes.

I entirely agree with the results of Mr. Henry Webb's experience that flanges should be strong, and have plenty of bolts through. I should not recommend the use of riveted flanges.

Short elbows for 12in. pipes are generally made of cast steel from motives of economy. The welded-on flanges have never failed in all the attempts to burst them off that have come under my notice, although, as I stated, the screwed-on flange has quite as good a record.

The general result of my experience of the strength of a weld in a steel pipe is that it shows quite as great strength as a steel plate, namely, from 22 to 26 tons per square inch.

With regard to the remarks of the President, that unless the surfaces were clean the weld would be defective, and if the weld were properly made there would not be any substantial diminution in the tensile strength of the material, I should like to point out that there is a very great difference between welding by hammering and welding by rolling. In the one case, the surfaces to be welded are pressed together over small areas by the percussive effects of the blow of the hammer transmitted through the thickness of the material. If we imagine a pipe welded thus for a distance of twenty feet, it will be evident that there would be danger of parts not being united or the dirt not squeezed out. But if you consider that the whole pipe is placed in a regenerative furnace at a uniform heat, and brought up to a welding temperature and then rolled over a mandril, which ensures a great pressure on every individual hundredth of an inch of the joint, and that this is done twice over it, it will be clear that the chance of a defective part of the weld is enormously

less. As the result of a short calculation, I find that I have been in daily contact with the welding and testing of upwards of 2,500,000 tubes, and I cannot recollect seeing a case of a defective weld owing to the surfaces to be welded being dirty. The causes of bad welds are principally a want in the material at the seam, bad quality of material, and over-heating of material. The first is very plainly seen; the second, being general, is usually easily found out. The last is due to careless workmen, and bad management. I have found by repeated tests that a good weld in steel or iron is substantially as strong as a rolled plate.

With reference to the communication from Mr. Samuel Boswell, no maker could do any more than satisfy himself, first, that the steel he was to use was suitable, and afterwards, by testing each pipe, that the welds were sound.

If the pipe were tested to nearly the elastic strength of the material while rapped by hammers, he would be fairly entitled to assume that the weld throughout was sound. If the working pressure were one-fifth of this test pressure, in my opinion, a butt strap would not be necessary, but would be a distinct disadvantage, and weaken the pipe. No motion that the pipes could be subjected to in practical working would affect a good weld so tested more than it would the solid plate, and if the bending were excessive the rivets of the strap would give trouble long before the weld did.

The case quoted in which personal damage or injury was sustained, owing to the escape of water from a burst pipe, would only occur where air was lodged somewhere or an accumulator used. If a hand pump were used to get up the pressure, I can testify from personal experience that, however close the inspector might be, the sudden escape of water would cause no injury. I quite endorse the remarks about pipes welded by

blacksmiths. In such cases the chances of defective welding are increased fifty-fold.

In concluding, I beg to thank the members of the Manchester Association of Engineers, for inviting me to place these remarks before them, for the kindly interest and attention they have accorded me while reading them, and for the remarks they have made and questions they have asked, which constitute a valuable part of the paper; and, in conclusion, for the very kind vote of thanks they have accorded me.

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5 Plates follow Illustrating this Paper.

UNIV. OF MICH.

UNIV OF MICH.

ELECTRIC POWER TRANSMISSION IN WORKS.

READ SATURDAY, MARCH 14TH, 1895,

BY

Mr. DANIEL ADAMSON,

(Associate Member of the American Institute of Electrical Engineers.)

HYDE.

Transmission of power from one dynamo as a generator to another used as a motor, is stated* to have been discovered in 1873, at the exhibition held at Vienna in that year, when a Gramme dynamo as a motor worked a pump, and was supplied with current from a similar machine through about a mile of cable.† As applied in workshops, however, it had its beginning, perhaps, ten years later,‡ and within the last five or six years it has developed so rapidly, both on the Continent and in the United States, that the writer has accepted the invitation of your Council to give a short description of what he has seen on both sides of the Atlantic, and also of what his own firm, Messrs. Joseph Adamson & Co., are doing in their works at Hyde. The reasons for the rapid development of electric transmission are briefly, the ease and economy with which power can be transmitted and controlled by its means, as may be instanced by the great number of electric street railways all over the world. In addition to these advantages are others that apply more particularly to its use in works, and it is with this branch of the subject that the writer will concern himself this evening.

* S. P. Thompson's fifth edition of Dynamo Electric Machinery.

† Martin and Wetzler's "Electric Motor and its Applications." Third edition.

‡ See paper read before American Institute of Electrical Engineers by Messrs. Crocker, Benedikt and Ormsbee, June 26th, 1895.

On the Continent there are several examples of electric transmission, some of which the writer has had opportunities of visiting during the last 18 months. Of these, perhaps the most important one, from our point of view this evening, is the plant of the National Arms Factory at Liège in Belgium, the particulars of which you have doubtless had before you often enough since the factory started, with such signal success as a new venture. There is, however, one piece of information I gathered while at Liège which I have never seen quoted, and that is, that the power required per rifle produced per day, is at Liège less than one half that required in the best of other factories using similar machines, but only equipped with mechanical transmission. At Liège there is also the Royal Arms Factory, where by installing one generating plant and replacing the separate steam engines by electric motors, they reduced the coal bill to one third. When I was in Belgium in 1894, the Company Veille Montaigne were just about to start a plant for electric transmission throughout their immense works. I understand it has fulfilled expectations and enabled the Company to reduce the engineers and stokers by nearly twenty men, from which the amount of fuel saved and wear and tear of engines avoided can readily be inferred.

About twelve months ago I was in Switzerland, which country is certainly the most important in Europe as regards electric transmission of power. While there I visited the large new shops of Escher Wyss & Co., which were then hardly complete; these works are driven by individual motors geared to the line shafts, and in addition to this, of course, the overhead cranes were electrically driven and individual motors were to be fixed for driving some of the larger tools. In a similar manner, although perhaps not to the same extent, electric power was being used at the works of the Oerlikon Machine Co. at Oerlikon, and of Messrs. Brown, Boveri & Co. at Baden At the latter

place, the motors were fixed to the sides of the steel pillars carrying the shop and belted to the line shafting, the weight of the motor being partially utilised to keep the required tension on the strap. In all these shops the polyphase system of electric transmission is used, for the reason that it is better adapted to the long distances over which the power is conveyed, these varying from 12 to 18 miles.

In Geneva the development of electric transmission has so progressed that they are even working electric cranes of so small a lifting capacity as thirty hundred-weight. These are used over the lathes and fitters' benches, to save the time and labour wasted in other shops by hauling at chain lifting blocks as is the usual practice in England.

In France and Germany also the development of the subject of this paper is proceeding, but the writer has not had the opportunity of visiting any installations in these countries. According to the technical papers, however, there is a particularly interesting installation at St. Etienne,* where motors are in use driving ribbon and velvet looms. At this place it has proved to be advantageous to use a motor for each machine, although the former are only about one-third of a HP, at which size the efficiency is found to be 55%. The proprietors of this plant, Messrs. Forest & Co., claim for it that the movement produced by electricity is more uniform and gentle than that obtained direct from steam, and, while the cost of construction is not greater, there is more economy in the maintenance of electric driven machinery than under any other system. Also in France electric travelling cranes were in use thirteen years ago. †

In the United States electric driving is quite common, and examples may be found in nearly every important town. In New

* Electrical Review, Vol. 36, p. 413.
† See Engineer, August 16th, 1889, page 134, first column.

York the De La Vergne Refrigerator Machine Co. put down a plant for driving an extension four years ago.* In the neighbourhood of New York are the two works that have figured occasionally in the papers as examples of electric driving, viz.:—The Crocker Wheeler Company at Ampere, and the C. & C. Electric Company at Garwood, both of which are entirely driven by electric motors. At both these places several interesting experiments have been tried as to the power required by various tools, the results of which their proprietors have generously published to the outside world.

In Philadelphia, the Baldwin Locomotive Works affords an instructive example of what can be done by means of electric driving. Two and a half years ago, on the occasion of my first visit to these works, the wheel turning shop was old, dark and low, and the wheels for the locomotives were rolled about and put into the lathes by hand, necessitating a dozen men being employed in nothing else but this labouring work. Now, they have raised the roof sufficiently to get an electric travelling crane overhead, and by this means the wheels are manipulated by two men. At the same time all line shafting was dispensed with, as it would, of course, have interfered with the traveller, and each lathe is driven by an independent motor. This first experiment has been so satisfactory that when I was there again about ten months ago they had on order a 250 HP dynamo and direct coupled engine, as their two 100 HP generators (one for the wheel shop and the other for their cranes) were getting too small. They were contemplating putting down three more similar plants of 250 HP each; room for even more than this was reserved in the new engine and boiler house. It was in these works that, three or four years ago, the two 100-ton electric travelling cranes, to travel up to 200ft. per minute along the gantry, were put down to lift the finished locomotives

* See p 683, Vol. 8, Engineering Magazine.

about the erecting shop. The advantages of this type were so apparent that the builders, Messrs. Wm. Sellers & Co., who make a speciality of cranes as one branch of their business, ceased in 1893 to build any other than electric driven cranes; the advantages claimed by them being practically no wear and tear, and the little attention they require compared with their previous cranes. In fact, I found electric travelling cranes almost universal two years ago, and where other types were in use, which was seldom, the proprietors were careful to explain that they had only just got them new before the development of the electric cranes.

In the neighbourhood of Pittsburg are the large works of the Carnegie Steel Company, who have extensively adopted electric travelling cranes, both for handling the ingots at the soaking pits, and also the finished girders in the stock yards. More striking, however, than the great number of electric cranes are the arrangements adopted for conveying the billets to and from the re-heating furnaces. In the first place, the traversing drawers, for charging the billets into the furnaces and withdrawing them, are operated each by two motors, one being used to travel the whole machine along the front of a line of furnaces, and the other motor to push forward or draw back the horizontal bar, which does the actual work of charging or pulling out the billet. The billet is pulled out on to a bogie, also operated by an electric motor, and the upper part of the bogie carries two or three live rollers on which the billet rests. The bogie is run by means of the motor connected to its travelling wheels to the end of the live road belonging to the train of rolls for which the billet is intended, and then a second motor on the bogie connected with the rollers on the top is set in motion in the required direction, and the billet is travelled on to the live road, which conveys it to the rolls. Even then, however, electricity has not done with it, because with the three

high rolls used at these works, the elevating tables on either side of the rolls, although they are raised and lowered by hydraulic power, are traversed across from one set of rolls to the next by means of motors, and the live rolls on same are driven also by motors. The whole of these operations are controlled by men stationed at switches wherever it has been found convenient to place them, and it is a very curious sight to see these masses of red hot steel handled by the machinery, acting apparently on its own volition, because of course there are no men near the actual place of operation.

On my first visit to these works, in 1898, they were experimenting with electro-magnets for lifting the plates for shearing, &c., but the plates could not be turned over with it as anticipated. At these same works preparation was being made to receive the large forging press from Messrs. Whitworth, and of course, in the interval between my visits, they had set this to work; otherwise, the principal alterations had been in the further development of the electric power distribution, and this same remark seems to apply to all the places that I was able to visit on both these trips; that is to say, that the bad trade during that period, had discouraged any extensions except on this one line of electric driving, in one form or another.

At East Pittsburg, a new settlement a few miles out from Pittsburgh, the Westinghouse Electric Company began to lay out an entirely new works a little over two years ago, as their previous place in Pittsburgh was not large enough. Eighteen months later the place was fully working and employing nearly 4,000 hands. These works are entirely driven by electric motors, which are generally bolted to the floor and belted up to the line shafts. This plant resembles what we should generally have in England, when we get so far, in that the power is generated from steam, as distinguished from Swiss

systems, which are usually water driven. The present generating plant consists of five 500 HP dynamos, each coupled direct to a Westinghouse engine. Two of these dynamos give continuous current, while the other three dynamos are on the two phase system, the reason for this division being that they require direct current for testing a great deal of this class of machinery, particularly for street railway motors. The bulk of the power transmission proper, to the extent of about 60 motors, is however driven from the three two-phase dynamos, and their experience has demonstrated the superiority of these Tesla motors over the direct current machines.

At Alliance, in Ohio, the Morgan Engineering Company have been building three-motor electric travelling cranes for about six years. At Cincinnati, there is a firm who have gone so far as to build lathes with reversible variable speed motors, fixed where the cones usually are, and they claim to get more power out of a given space by this means than by the old system of belt driving; this is no doubt explained by the very slow speed the belt of a lathe usually runs, although the motor will of course also have to run the same speed; but apart from the heavier cuts that can thus be taken, no one will dispute the greater handiness of a lathe in which the speed can be altered or the direction reversed, simply by moving a switch handle, when compared with the trouble of shifting belts.

When in the States in December last, I availed myself of an opportunity to call and see the works of another large electric company, viz.: those of the General Electric Company, at Schenectady. Here I found what seemed to me the most striking argument in favour of electric driving, in that they have been using this system of power transmission for the last six years, and have not advertised the fact as much as many firms there who are not transmitting, perhaps, a tenth of the amount, and yet who appear very often in the technical press.

There is always a doubt in the mind of an outsider who sees an electric firm going in strongly for electric driving, that it is being done more as an advertisement than to serve any other purpose, but in this case, at all events, the suspicion would have no grounds, and it is evident the General Electric Company have adopted electric transmission on its own merits.

Their power house can turn out about 2,000 HP, and this is divided up over a number of sizes and types of generators. As this visit was paid only a few weeks subsequent to the reading in this room of Mr. Worthington's paper on "Electric Locomotives," I was of course particularly interested in the three large locomotives this firm had built for Baltimore tunnel, and as I had to go to Baltimore the next day I obtained permission to visit the tunnel and power house there. For a description of this plant reference must be made to the technical press, and it will be sufficient for me to say that the generating plant and the two locomotives already delivered, were working satisfactorily, in spite of rumours to the contrary current in this country. An opportunity was afforded me of riding through the tunnel on No. 2 locomotive, which had only been delivered a week or two, and we went through in both directions, a distance about 1½ miles each way, but without any load, there being unfortunately no train waiting to be hauled through at the time. The only figures I remember of the great number the guide gave me, were those representing the maximum power recorded as having been developed by one of the locomotives when accelerating a heavy goods train after stopping on an incline, and this amounted to nearly 4,000 electrical HP, and when delivering this the three generators in use were working at 100 % above their rated capacity.

In England, we only appear to be beginning with electric driving, the principal installation that the writer has visited being that of Messrs. Siemens Bros. at Woolwich, who com-

menced alterations about three years ago, and have installed generators direct coupled to high speed engines amounting to 1,200 HP in the aggregate. The result has been that Mr. Alexander Siemens was able to state twelve months ago that they were saving then about 3,000 tons of coal per annum, and the wages of six stokers and engineers, although they had not completed their changes.*

At Middlesborough, the Bedson Wire Co. have installed a 600 HP dynamo coupled direct to a triple expansion marine type engine running 160 revolutions per minute, and are driving about forty machines by separate motors, and also their cranes. These works were running quite satisfactorily on the occasion of my visit a few months ago. Messrs. Dorman, Long & Co. are near neighbours of above works, and have at work a 225 HP direct coupled dynamo and engine running 350 revolutions per minute, the power from which is distributed to over forty motors driving punching, shearing, drilling machines, circular saws, live road gear, line shafting, and in fact all the miscellaneous requirements for power in such a works. The result has been so satisfactory that the firm have on order plant sufficient to double their present output of electric power.

And now to turn to what we are doing at Hyde, I may commence by saying that we first began to seriously consider the matter of electric driving about three years ago. We required then to increase the number of the travelling cranes, and it was found that the existing engines were not powerful enough to take the increased load that would be thrown upon them with the addition of the two or three cranes desired. Our attention being thus forcibly called to the matter, we found that electric driven cranes were considered, in other countries at any rate, to be more economical in this and other respects than other types of cranes. We therefore put down a combined engine

* See paper read by Mr. Alexander Siemens at Newcastle, December 8th, 1894, before the Federated Institution of Mining Engineers.

and dynamo, which was considered would be large enough to drive the cranes we had in view and leave a sufficient margin for lighting as well, and our intention was to double or treble this "unit" as further developments required. It was found however that the first three electric cranes (the original number we thought of introducing) worked so satisfactorily that we decided to increase the number, and as in the meantime it had been found advantageous to increase the application of electric transmission of power in other directions, we have been compelled to enlarge our original ideas, and have now in hand a 75 kilo-watt dynamo, which will be coupled direct to a 100 B HP Belliss engine running 400 revolutions.

One of our first applications of electric power, apart from the cranes, was to put down a small motor to drive Green's economiser, which had been previously driven by means of a long cotton cord stretched across an open yard; this gave a lot of trouble owing to the variations in length that took place according to the state of the weather, and although this difficulty was overcome by adding a compensation arrangement, yet the wear and tear on the rope was so great that the renewal of it was quite a serious item for so small a matter.

We were very anxious to have a motor applied to a new boiler shell drilling machine with eleven drills, made nearly two years ago by Messrs. Kendall & Gent, but at that time we could not obtain a suitable one for the purpose at a reasonable price, and it was only after the machine had been at work some months that we got into communication with an American electrical firm (the Card Electric Company, Cincinnati, Ohio) who appeared to make what we required. The result was we gave them an order for one, and it has now been driving the machine satisfactorily since last September. It will, no doubt, be of interest to you to learn that the armature of this motor, when it was put into place,

was found to be an exact sliding fit on the shaft of the machine, although one had been turned in Manchester twelve months before and the other had been bored in Cincinnati, 4,000 miles away, to a dimension cabled out to them, thus speaking volumes for the system of gauges established by Whitworth. As the requirements of this machine are rather special, a description might be interesting. The drilling machine, as originally designed by the makers, required three driving belts, viz.: one for advancing the drills rapidly up to their work, one for doing the actual drilling at a slower speed, and the third for withdrawing the drills. To couple a motor direct to this machine as desired, so as to entirely dispense with straps, necessitated that the motor should run in both directions, and in one of the directions at two different speeds, and the same must be controlled by one handle, just as the belts were in the first instance, so as not to be more complicated in manipulation; because, when making alterations of any kind in works it is advisable to simplify the actual manual labour rather than otherwise, in order that the workman may not be prejudiced against the change. By the application of this motor we were enabled to dispense with the belts and the wear and tear on same, and also the great number of pulleys, all of which were running the whole time the engine ran. When a belt broke down it was necessary to slow down the engine to get it on again, on account of the weight of the belt and the large size of the pulleys, besides the loss of time of the machine while the belt was being repaired. Now when the machine is not working there is nothing moving in connection with it, and therefore no wear and tear.

Another application we made of electric power was to a small sensitive drill, and although it was not considered advisable in this instance to entirely dispense with belting, yet there is far less leather about this machine than about one driven in the ordinary way.

More important, however, was the application of motors to the hoists in the rivetting tower, which enabled us to stop entirely about six belts and fifty or sixty feet of shafting constantly running under the old arrangement, beside giving the men something that was more under their control for the small adjustments of height required when riveting up shells; while, at the same time, it enabled them to hoist and lower through greater distances, as when adding another ring, at a higher speed than could be done with a strap-driven hoist that was of course always working at the same speed. Also the wear and tear on the belts driving the hoists was very great owing to the high speed they ran, and the constant shifting they were subjected to during the operation of riveting.

I may here mention a curious fact brought to light in connection with these hoists, that illustrates an advantage of electric driving which could only have been found out by actual trial, and was not likely to be discovered by any amount of theoretical reasoning or calculations, and that is that belts in such a situation as above lasted longer and broke down less frequently when driven by an electric motor than when they were driven through a series of belts from the shop engines. The reason for this we have failed to make out, and I can only therefore give you an account of the circumstances. The two hoists referred to above were originally driven from one short counter shaft, two belts (one open and one crossed) going from the counter to each set of hoist pulleys, and this counter-shaft was originally driven from the main line shaft of shop by a train of three belts and two lengths of shafting. As soon as we had electric power at our disposal and before the special motors were ready for direct coupling to the hoists, it was decided to save running some of this train of shafting and belts by temporarily installing a motor belted direct to the short counter-shaft; this motor, of course, ran practically

continuously, as when one hoist was not in operation the other generally was, and yet under these circumstances reduced wear and tear was found on the open and crossed shifting belts than when they were driven in the previous manner.

Our most important application of electric power up to the present has been the driving of the over-head travelling cranes, and no doubt some particulars of the powers and speeds of those will be of interest:

	Lifting capacity of Crane	30 tons.	10 tons.	5 tons.
	Span of Crane	45 ft.	45 ft.	45 ft.
	Approximate weight of Crane..	24 tons.	14 tons.	6½ tons.
Hoisting.	Hoisting speed per minute *light*.....	5·7 ft.	17·4 ft.	30 ft.
Hoisting.	Ditto, fully *loaded*	2·4 ft.	7·3 ft.	13·1 ft.
Hoisting.	Power absorbed at above speeds, *light*	3·7 H.P.	3·6 H.P.	3·7 H.P.
Hoisting.	Ditto, fully *loaded*	9 H.P.	9·6 H.P.	10·4 H.P.
Longitudinal travelling.	Travelling speed per min., *light*.....	68 ft.	88·4 ft.	144·8 ft.
Longitudinal travelling.	Ditto, fully *loaded*	41 ft.	67·4 ft.	132·2 ft.
Longitudinal travelling.	Power absorbed at above speeds, *light*	3·3 H.P.	2·6 H.P.	2·5 H.P.
Longitudinal travelling.	Ditto, fully *loaded*	5 H.P.	3·3 H.P.	2·8 H.P.
Cross traversing.	Traversing speed per min., *light*	38 ft.	68·6 ft.	66·8 ft.
Cross traversing.	Ditto, fully *loaded*	20 ft.	40·6 ft.	59·3 ft.
Cross traversing.	Power absorbed at above speeds, *light*	1·5 H.P.	·7 H.P.	·48 H.P.
Cross traversing.	Ditto, fully *loaded*	3·1 H.P.	1·35 H.P.	·85 H.P.
	Hoisting.—Efficiency at full load	54·3 %	51·3 %	46·9 %

The only figures I have for comparison with above are taken from a paper read about 14 month ago, by Mr. John Barr, before

the West of Scotland Iron and Steel Institute, and he gives the results of a series of experiments made on various cranes under ordinary working conditions. Taking the two travelling cranes that gave the best results, he found that the power required to drive the rope alone varied from 5·9 indicated HP to 6·8 indicated HP per hundred feet length of shop; the ropes running 2,200 feet and 1,570 feet per minute respectively. Our own experiments with the high speed ropes of our old travellers gave from 5 to 6 indicated HP per 100 feet length of shop, the shops being somewhat longer than those mentioned by Mr. Barr. This means that to obtain corresponding speeds with rope driven cranes we should have to add, in a shop 200 feet long, at least 8 or 10 HP to the figures given for the period of the actual operation, and for the rest of the time the crane is in use, although not actually working there will be about 11 HP being constantly absorbed for every rope running; as against, in the electrical plant with three motor cranes, the proportionate share of the small amount of power required to keep the engine and dynamo spinning round. It is more particularly in these intervals of rest that the advantages of direct coupled electric driven machines of any kind become so apparent.

Since electric power has been at our disposal in the works it has been found very convenient, on special occasions, for driving individual machines that may be required to run night and day, or in special positions in the shop, for a period. On such occasions we now only require to run during the night the comparatively small generating plant, which provides not only the power to drive the machine but an abundance of light for the men to work by, and also enables them to make use of the overhead cranes for moving the work when necessary; this dispenses with the great waste of coal and oil entailed formerly by running the large engines and all the shafting, belts, &c.

For the advantages of electric driving I do not think we ought to look to any possible saving in fuel, at any rate in ordinary workshops, although I believe this will nevertheless follow its application. The actual expenditure on fuel for power purposes alone, however, is so small that even a reduction by a large percentage would mean very little compared with the other items of cost of production. But, in this connection, it must not be forgotten that with almost all methods of transmission a loss of power through friction implies at the same time a deterioration of the apparatus, or otherwise wear and tear, and as the *friction losses* of electric transmission are very low, so accordingly is the life of the apparatus found to be very long. It seems to be pretty generally acknowledged by the exponents of mechanical transmission, as required in an industrial establishment, that the losses through friction on the transmission itself amounts to say 20 to 25% under the most favourable conditions, or about the same as would be guaranteed by first-class firms for electric transmission on a reasonable scale. As the losses of the electric system are principally made up of heat losses in the dynamos and motors, which does not cause any deterioration in first-class machines when kept within reasonable limits, it follows that fuel used up in the friction of mechanical transmission is worse than wasted; it is spent in wearing out the ropes, belts, brasses, &c.

As to the amount of this power lost in friction there are several very different ideas prevalent, this no doubt being due to the varying nature of the work carried on in different establishments and correspondingly different amounts of power used for a given result. On the next page is a list of powers required by different works in the United States, which perhaps most of you will have seen quoted before.

LIST OF POWERS.

NAME OF FIRM.	NATURE OF WORK.	Total.	To drive Shafting.	Per cent. to drive Shafting.
J. A. Fay & Co.	Wood Working Machinery	100	15	·15
Union Iron Works	Engines, Mining Machinery	400	95	·23
Frontier Iron and Brass Works	Marine Engines, &c.	25	8	·32
Baldwin Locomotive Works	Locomotives	2,500	2,000	·80
W. Sellers & Co. (one Dept.)	Heavy Machinery	102·45	40·89	·40
Pond Machine Tool Co.	Machine Tools	180	75	·41
Yale and Towne Co.	Cranes and Locks	135·05	66·81	·49
Ferracute Machine Co.	Presses and Dies	35	11	·31
Bridgeport Forge Co.	Heavy Forgings	150	75	·50
Hartford Machine Screw Co.	Machine Screws	400	300 (?)	·25 (?)

The above was compiled by Mr. J. J. Flather, and is quoted here from the *Engineering Magazine*, vol. viii, page 670. The results obtained are quite confirmed by tests in our own and other works where we found the friction losses, as measured

by indicating the engines when only driving main shafting and belts, amounted to quite 60% of the normal working load, and in our own case there might be added formerly a further 30% on account of the ropes for travelling cranes, the power used in driving which was of course all lost in friction.

One of the advantages of electric transmission not yet touched upon in this paper, because it does not concern our own business so much as some others, is the regularity of driving obtained by its means.

In order that you may realize the regularity of driving obtained from electro motors, I would refer you to the development of the electric lighting industry, and to the concurrent improvement in steam engines, more especially those of high speed, and in the governing of same. These improvements were necessary on account of the great variation of light emitted from the incandescent lamp, caused by a comparatively small variation in the voltage; thus speaking approximately, a variation of 2% in the electromotive force of the supply current will cause an increase or decrease of 10 to 12% in the candle-power of the lamp. Having therefore now obtained the necessary regularity of the primary motion, as is shown by the steadiness of incandescent lamps, we can absolutely depend upon a similar regularity of motion in the electro motor, which is simply a dynamo reversed. Further, the speed of the motor being comparatively high, and the force or torque being applied *equally* and *constantly* around the periphery of the revolving armature, the motion is not subject to those periodic variations which, for instance, is found in steam engines having a long stroke and running at a low speed.

There can be no doubt as to the great benefits of steady driving, although they are possibly greater in such cases as a spinning mill, for example, than in a workshop. Even in the latter, however, the advantage of keeping the machines always

up to the normal speed, under the heaviest loads, is sure to make a difference in the output when compared with a system of transmission that is liable to ease off when called upon for full duty, and which is subject to every change in the condition of the atmosphere.

Another advantage already incidentally referred to, of having electric power at your disposal, is the convenience of having light and power from the same source, because there is no doubt that the advantages of electric lighting for workshops and mills are now proved beyond dispute.

Another point worthy of consideration is that all successful businesses call for alteration or extension of plant some time or other, and this is generally looked forward to at the time of laying down even the first portion. But it is always an advantage and often a necessity, that at the beginning an undertaking should not be handicapped by any unnecessary expenditure. Yet this can hardly be avoided when making plans for mechanical methods of transmission, because any increase of power required after the full capacity of the original plant has been reached, can only be met either by the very costly method of re-placing existing engines, shafting, &c., by larger ones, or the wasteful one of putting down another set similar to the first, which must necessarily be placed some distance from the boilers. Now, in the case of electric transmission this is unnecessary, as the boiler house and engine house can stand side by side, at such a distance from the works as to allow any desired amount of room for extensions, and as more power is required it is only necessary to add suitably sized units to those already installed, and the whole power plant is kept close together where it can be properly and economically looked after.

Also, in the case of alterations to existing works where electric power is available it is so very simple to fix a motor temporarily,

to drive a portion of the plant that would otherwise be cut off and have to stand idle, that it is becoming customary, even in England, in places that are usually mechanically driven to adopt electric power temporarily to drive portions of the plant during alterations, and thus keep the output of the whole establishment balanced. Then again there are no doubt hundreds of workshops that want re-modelling, and one of the principal obstacles to it is that the present method of driving is not sufficiently elastic, both to fit the place during the alterations and subsequently; in these cases, it would be well to consider electric transmission. In fact, in most establishments, the question of power transmission is found to be a matter of almost the first importance, instead of being only a secondary matter, as it ought to be, because after all, the shafting, &c., exists to drive the factory, and not the factory to hold the transmission plant.

DISCUSSION.

The PRESIDENT (Mr. J. Nasmith) said that during the week he had had an opportunity of seeing what Messrs. Adamson were doing at Hyde, and could, for the most part, confirm what had been said in the paper as to the system of driving. He might mention that there was an electric transmission installation at Messrs. Howard & Bullough's, Accrington, which had not been referred to in the paper. The above firm had built a new wing a short time ago, and being in some difficulty as to how to obtain the necessary power, they had put down a "unit" as a sort of experiment, and finding it answered their object very well, they were gradually extending the system throughout the whole works, by breaking up the shafting into sections, and driving a specified number of machines from one motor. This

system enabled them to deal in detail with orders in a manner which was previously impossible. When the installation was completed and the works were fully laid out on this system, it would probably be the largest of the kind in the kingdom. The shafting was retained, but divided into sections, one motor driving a certain section; but whether in that way they got the full advantage of the electric system was of course open to question.

Mr. Z. TETLOW said that at the L. & Y. Ry. Loco. Works, Horwich, there were twenty 30-ton cranes in the erecting shops, and they had converted six of them into electric-driven cranes. These were such a success that they had decided to take all the shafting and ropes down, and convert the whole of the cranes. The cranes were remarkably similar to the 30-ton cranes mentioned by the author, both as regards weight, span and speeds. He could confirm the figures mentioned as to power required to drive ropes from indicator diagrams, as well as electrical tests.

Mr. T. DANIELS (past-President) said the sooner the system was developed and made more practicable the better it would be. In the old methods there was such a large percentage of loss that it was time some new system was introduced.

Mr. FRANK REED observed that the author had taken very bad examples of rope driven cranes, when he stated that it required 5 to 6 HP to drive a crane rope for every 100ft. length of shop. In the works with which he was connected, there were ten cranes with a collective capacity of 202 tons, and an aggregate length of shop equal to 1,350ft. According to the writer of the paper the ropes for these cranes would take 81 HP to drive them light. They had however only 120 HP available, so that if the author's statement were correct, only 39 HP would be left to drive 300

machine tools, 1,320ft. of line shafting, and do the work of the cranes. The 6 HP was therefore much too high for any well-constructed crane. Of course there were rope cranes and rope cranes, and he had seen both very good and very bad examples, but he thought he might reasonably say that for an ordinary crane rope the power mentioned was much too high.

Mr. SAMUEL BOSWELL said he had been through the works of Messrs. Adamson, also of Dorman, Long & Co., both before and since electric driving had been adopted, and he was satisfied that the alterations were beneficial as compared with belt driving.

In works of this description where long bars, plates, and large angle rings were being handled and carried about, overhead belt driving was often a great hindrance to the men, and as belts were now entirely dispensed with, greater facilities were offered to the men, and much time saved in raising and lowering work in passing machines. The boiler and bridge yard generally was of such a character that if electric driving could be successfully applied as it had been in the two works mentioned, there was no doubt it could be successfully applied anywhere. The overhead lifting gear for riveting machines and travellers was all that could be desired and difficult to improve upon.

Mr. SAMUEL DIXON (past-President) said he noticed that Messrs. Adamson were using the reversing motor with good results. Personally, he found that electricians generally were opposed to reversing motors, and when asked the reason gave a very vague reply. From a mechanical point of view, reversing was a very important point indeed. Take the motor applied to a boiler drilling machine, which, under severe conditions, had to reverse every minute, with two speeds; if it would reverse under those conditions it would reverse under almost any. He

could not understand why electricians objected to reversing motors. He had had some experience with a motor driving a 12 or 14 HP machine, with about eight variations of speed, and he was struck with the simple way in which variations could be effected. Certainly, in some directions there was a great field for the adoption of electric driving.

One point on which he would like some information was as to what was the best voltage to work at in an engineering shop. Of course 120 was quite safe, but he would be glad to know whether it was safe to work at 200 or more. Was there any uniform voltage for electric transmission in engineering works which it would be well to adopt, analagous to the pressure of 750lbs., which had been so generally adopted where hydraulic transmission was used.

With regard to the HP absorbed by cranes and machines, he thought if these were tested electrically it would often be found that they were getting more HP through the machine than was imagined.

Mr. Isaac Simpson said he gathered from the paper that the author would advise the adoption of electricity in nearly all circumstances. Personally he thought electricity should be used, and not abused. Mr. Adamson seemed to recommend electric cranes very largely, and some of his American friends had practically apologised because they did not happen to have them. No doubt electricity was very useful for cranes, but other powers were equally so, and he (the speaker) thought that circumstances and conditions ought to be taken into account before fixing upon the motive power for the crane. He was glad the "rope" question had been raised, as it was essential that these matters should be absolutely correct. He congratulated the author on the efficiency of his 30-ton crane, *i.e.*, 54·3 per cent. when fully

loaded, which was exceedingly good, and he should like to know what kind of gearing was used.

It would appear from the paper that the author thought three-motor cranes were the best. Mr. Simpson admitted that the three-motor crane described by the author worked efficiently, and was much cheaper than the one-motor crane; at the same time the latter, although rather more costly, was much more durable and gave more general satisfaction.

Mr. JOSEPH ADAMSON said the last speaker was under a misapprehension. A three-motor crane was not cheaper than a single-motor crane and had less wear and tear. To put down a single-motor crane on which the motor was continually running when the crane was in use whether any work was being done by the crane or not, was in his opinion a mistake, in fact he looked upon such a contrivance as a cross-bred affair.

A great deal had been said about the power required to drive the rope of a travelling crane, but the important fact had been overlooked that, whether this power was large or small, it was all wasted and represented so much wear and tear which did not arise with a three-motor crane, where everything was at rest between the operations while the men were adjusting chains, &c. The case mentioned by Mr. Reed, where they had ten ordinary cranes and 300 machine tools with only 120 HP to drive them, would certainly be hard to beat by any system of electric driving, but his own experience had been that 300 machine tools of such a type as required ten travelling cranes to attend to them, would alone absorb a great part of the 120 HP said to be available, and he would ask whether the power named had been obtained by actual careful tests.

Mr. E. G. CONSTANTINE observed that some years ago Mr. Trail, the engineer of the Portrush Electric Railway to the Giant's Causeway, informed him that by reversing the motors on the

cars they could bring the latter up on a down grade without the application of the hand brake, but this course would only be adopted in cases of emergency owing to the danger of breaking the magnets in the dynamos at the turbine generating station. With regard to the power absorbed by cranes, as Mr. Reed had remarked, there were cranes *and* cranes; and although of course Messrs. Adamson's shop was well arranged, he feared that taking the general run of boiler works, it was hardly fair to compare them with works like Craven's or West's, and the power absorbed might therefore be greater than in the two last-named cases.

The question brought forward by Mr. Adamson was one of very great importance to engineers, and there were many purposes, in connection with boiler making, to which electric driving could be economically and satisfactorily applied. If there was any inaccuracy in the statements made in the paper as to HP for ropes, &c., he was quite sure Mr. Adamson would check his results, so that the correct figures could be arrived at.

Mr. HANS RENOLD referred to the use of chains for gearing a line shaft up to a dynamo. Belts had been used for this purpose, but with no very satisfactory results. With chains they obtained a positive connection, together with a certain elasticity which was very advantageous in connection with high speed machines.

Mr. JOSEPH ADAMSON suggested that the discussion should be adjourned in order to enable members to take diagrams as to the power required for driving rope cranes in their various shops. In most of their shops, however, the difficulty was to take a diagram which showed 3 or 4 HP, this representing only the thickness of a line; sometimes, without any doubt, rope driving used up a good deal of power.

The PRESIDENT said he did not think there was any necessity to adjourn the discussion. Any further observations by members could be published in the transactions.

Two points seemed to come out of the discussion that evening. One was that the chief value of electric driving was shown in cases where an intermittent supply of power was required. The saving of power was due to the fact that it was not necessary to absorb the power during the whole of the time the works were running, but it could be applied just at the moment when they wanted it, and in precisely the amount required, no waste occurring other than that caused by getting the motor up to speed. As soon as the power had served its object it could be shut off until required again.

The other point to be noted was this:—The difficulty with electric driving had been in machines where it was necessary to give two directions of motion. Electricians, however, could scarcely be induced to give them a motor which would reverse, and he had had experience of this during the last few months. One of the chief things in Messrs. Adamson's shop, however, were these reversing motors, which could be switched on so as to give two directions of motion, and in carrying this into effect the firm had gained an important advantage, for which the whole engineering community ought to thank them. He should just, at this point, like to give a word of advice to electrical engineers. The bulk of those engaged in electrical work were gentlemen who were electricians and not engineers. Now he would suggest that the right training for the men who were about to be engaged in this specific work was, first, a sound engineering training, so that they would be well acquainted with the principles and practice of mechanics, and then they might graft on to that a study of the science and practice of electricity. If that were carried out, electricians would accomplish far more than they had done, great as that had been, and would never be

at a loss, as was at present frequently the case, when their attention was directed to something which required the application of mechanical skill. He hoped any electricians who were present would take that advice to heart.

With regard to the use of chains for the transmission of power, there was more in it than many might think. Certainly the difficulty of driving dynamos at a high speed and shafts at a low one, could only be overcome by using some means of transmission which was at once elastic and rigid, and they might have to look to the chain maker, and not to the belt or rope maker, to attain the desired result.

The President concluded by moving a vote of thanks to the author for his admirable paper, remarking that he had worthily sustained the honourable traditions connected with his name.

Mr. Alfred Saxon seconded the motion, observing that papers such as that they had listened to served to waken engineers up. He hoped some of them would follow the example furnished by the well-known firm with which Mr. Adamson was connected, by taking a similar course of action at their own works.

Mr. Percy Nicholls, in a subsequent communication, desired to make a few remarks on the electrical side of the question, especially with reference to the motors.

First, with regard to the best voltage to adopt. As far as economy was concerned, the voltage did not affect the efficiency of the motors themselves, and a high pressure, owing to the improved insulation required, might even increase their first cost, but for a given loss of power in the distributing mains, the higher the voltage the smaller the cables would be. In most cases of electric driving in works the distance of the motors from the generators was only small, and the extra expense of cables for a low voltage was only a small part of the

total cost, so that it was preferable to use a low and perfectly safe pressure. There was no doubt that anything less than 300 volts was perfectly safe, and no pressure much less than this should be used except for other reasons. That which most influenced the pressure was the need of utilizing the power mains for the lighting as well, and this, in the past, had kept the pressure at 110 volts, but now that reliable 220 volt lamps were on the market it was advisable that this should be adopted as the standard, thus getting the increased economy in mains.

On the other hand it was desirable, if possible, to have a separate dynamo and circuit for the lighting, driven by its own engine or supplemented by accumulators, so that the lights could be used when the main part of the works were closed. This was especially the case where any large motors had to be frequently stopped and started, as the fluctuations of pressure produced in the mains might damage or destroy the lamps.

The author states in his paper that the polyphase, chiefly 3-phase, system was used for the reason that it was better adopted to the transmission of power to long distances. This was, however, only one of the minor advantages of this type of machine, which was now becoming almost universally adopted for power purposes on the Continent and in America. Beyond the advantages which could be obtained in the generator, there were some special points in the motors, the chief of which was the simplicity and rigidity of their construction, especially of the rotating parts. They had none of the complicated endwindings or cross connections which were often found in continuous current machines. They had no commutator, nor was any current conveyed to the rotating part, thus doing away with any possibility of sparking, with its consequent damage and wear. Those who had used continuous current machines would know how, especially when used in dirty places or when much over-loaded, the commutator would wear abnormally and

require to be often turned up. The amount of attention these three phase machines required was a minimum, since the only possible place of wear was the bearings, and with the continuous lubrication and large oil reservoir now in use, they might run for weeks without being touched. Another great advantage was the regularity of speed, since they could be guaranteed not to vary 5% between no load and full load. They, moreover, gave a large torque at starting, and could be run in either direction equally well. Their efficiency was very high, and they were lighter for a given power and speed than a continuous current machine.

The first plant on the 3-phase system was now being installed in England, and it was certain that they would in the future be generally adopted for power transmission.

There was again the question of reversing motors. Taking first the case of continuous current machines, there were four objections which caused electrical engineers to prefer that the reversal should be done by mechanical means. The first and most important was that, for a given current there was one position of the brushes which gave the minimum amount of sparking, and the larger the current, the further was this displaced from the middle, so that if the direction of rotation were reversed it was evident that the brushes should be moved, so as to have an equal lead on the other side of the mid position. It was possible that this adjustment of the brushes should be done automatically, but of course this introduced complications, and the way usually adopted was to put the brushes in the mid position, so that in this case there would be a certain amount of sparking in either direction of running, with a corresponding increase of wear of the commutator. A second reason was, that on starting and stopping a larger current passed through the armature, with a possibility of damage, especially if the reversing were done quickly. A third reason, with larger

motors, was that on starting it was necessary to introduce a resistance into the armature circuit to prevent too great a current, and this resistance had to be gradually removed, so that a quick reversal was not possible. The fourth reason, and perhaps the most influential, was that if any wear or damage was to result through reversal, the electrical engineer would prefer to see it take place in the mechanical part and not in the motor.

With 3-phase motors it was a much simpler matter since having no commutator the most important objection did not hold. As an example of this, there was at work a 65-ton crane, made at Oerlikon, with three motors, all of which reversed; moreover, it could raise or lower, or travel down the shop at two different speeds. This firm had made nearly 200 cranes working on this system.

In conclusion, it was certain that highly efficient and well constructed motors might be obtained, and a great deal depended on those who adopted this system of driving to perfect the methods of gearing down, and adapting them to the various types of machines they are to drive.

Mr. W. J. JENKINS said that as he could not understand where so much power as 6 HP per 100ft. of rope could be wasted with a rope crane, he had indicated that day an engine driving a rope crane only, and would now give the particulars of the power for the general information of the members.

The engine used for driving the crane was a gas engine by Messrs. Crossley Bros., Ltd., of seven nominal horse-power, having a cylinder 8½in. bore by 18in. stroke, and making about 175 revolutions per minute. Great care was taken with the indicating, and each test was repeated three times. The engine drove a length of about 40ft. of shafting across the end of the shop, and the countershaft of the crane rope-gear was driven

from a pulley at the end of the shaft by means of a belt 3in. wide. The driving rope was $\frac{7}{8}$ths of an inch diameter, the distance between the centres of the end pulleys being 193ft., the tension weight at the end of the rope was within a few lbs. of one hundredweight. The total weight of the rope would be about 86 pounds, it being supported at intervals of 15ft. on light cast-iron rollers about 6in. diameter. The crane was made by Messrs. Craven Bros., Ltd., being one of their ten-ton size.

1.	Power to drive engine alone	3·1	I.HP.
2.	Power to drive engine with belt, 40ft. of shafting, and belt of countershaft on loose pulley	4·64	,,
3.	Power to drive engine with belt, shafting, countershaft, rope, and six belts on crane, all running idle	6·87	,,
4.	Power to drive engine with belt, shafting, countershaft, rope, belts, and crab hoisting at slowest speed of 3ft. 4 per minute	7·106	,,
5.	Power to drive engine with belt, shafting, countershaft, rope, belts, and crab hoisting a load of 3 tons, at slowest speed of 3ft. 4in. per minute	7·823	,,
6.	Difference between (2) and (3) being power required to drive rope alone and idle belts	2·23	,,
7.	Power per 100ft. length of shop	1·15	,,

There was considerable difference between the author's estimation of 6 HP per 100ft. length of shop, and the figure 1·15 HP found by indicating an engine doing nothing else but driving the crane. In Mr. Jenkins's opinion the latter figure was much more probable than the former, providing the drive

was a direct one and well arranged, for it was difficult to see where so much power could be wasted without showing its effect in undue heating.

The speed of the rope was about 1,850ft. per minute. Owing to the smallness of the engine it was not difficult to balance up the power from known limits. For instance, on one occasion the crane lifted a boiler weighing 13 tons and travelled it along at the same time, but the engine was then taking the total possible number of explosions and was loaded to its maximum. Now the makers' list states that the engine will indicate a little over 14 HP as a maximum. Following the proportions given above we should have:—

Power to run the engine, shafting, and rope empty, as before	6·87 I.HP.
Power to lift 13 tons at 8ft. 4in. per minute	4·129 ,,
Estimated power to propel crane and load at 124ft. per minute	3·000 ,,
	13·999 ,,

As a matter of some interest bearing upon the cost of power for driving such a crane, Mr. Jenkins mentioned that careful quarterly tests were taken of the gas used by the above-mentioned gas engine during the year 1892. The average cost per hour was 3·08 pence, the amount of gas used being 102·69 cubic feet, and the price at that time 2s. 6d. per 1,000 cubic feet. The crane was almost constantly employed, though the loads were generally under one ton and were consequently lifted by the single chain at 20ft. per minute. The crane-driver attended to the gas engine as well as the crane.

While in every sense of the word anxious to see Englishmen availing themselves of the many very excellent applications of electricity to driving purposes mentioned by the author, yet he did not think the prejudices against it would be overcome by

condemning wholesale what had answered admirably up to the present; particularly, when the difference in first cost would be largely against the electric method, though that might be balanced by greater convenience. It seemed to him that electric driving would find its widest field, not in existing works already fitted up with engines and shafting and lighted by gas, but in new works where everything could be arranged to suit it, without sacrificing tolerably efficient plant, and where the lighting of the works could be amalgamated in one comprehensive scheme with the power.

It appeared to be a fact that wherever electric driving had been adopted it had been extended, and this notwithstanding that the electrical advocate always spoke in a very lighthearted fashion of "units of 100 HP." One such unit each would probably be more than sufficient for 75 per cent. of the engineering works in England.

He hoped to see the extended use of electricity in new works as pointed out by the author.

The AUTHOR, in replying, said the discussion appeared to divide itself into two very distinct parts, viz., a critical and a confirmatory side. It was a source of gratification to him to notice that those who spoke favourably of the subject of the paper were those who had had some experience of the matter, either from seeing the works of the writer's own firm, or other establishments where electric transmission had been adopted. To take each of the speakers in something like order, he would commence by thanking the President for his favourable remarks and for mentioning the works of Messrs. Howard and Bullough. These were not included in the paper, because he was not able to lay before them any definite information of moment in connection with this plant.

Thanks were also due to Mr. Tetlow for his remarks confirming the figures given in the paper regarding the power to drive the ropes of cranes, and which had given rise to the bulk of the subsequent discussion.

Mr. Daniels had spoken of the advantages of waiting a little, and not rushing into every new thing that turned up, and this seemed to be one of the characteristics of the English nation generally.

The object of the paper had been an endeavour to demonstrate that electric driving was now far beyond the experimental stage, and should be seriously considered by anyone interested in economical production.

Mr. Reed had accused him of taking very bad examples of rope cranes, but, as stated in the paper, they were the only examples at hand. He was quite sure there were many cranes at work which would show worse results, and he believed he had quoted fair samples. In fact, as he had said, he cited the two best mentioned by Mr. Barr, and a recent letter from that gentleman assured him that the tests were carried out with care.

He appreciated Mr. Boswell's remarks pointing out the higher requirements of boiler shops for rapid handling of the work, as compared with the ordinary run of engineering works. The thanks of the meeting were due to Mr. Jenkins as the only speaker on what might be called the opposition side who had furnished them with any actual figures from tests. These, however, were based on one morning's tests with a gas engine, and the author feared the results could hardly be expected to be accurate to the third decimal point as the figures appeared to indicate.

Assuming Mr. Jenkins' figures to be correct, he found that the capacity (or ability to transmit power under ordinary

working conditions) of the rope given at the stated speed was about one-half that of the ropes on Messrs. Adamson's own old travelling cranes, and only about a third of that on one of Mr. Barr's cranes; so that, taking into consideration the well-known fact that a high-speed rope was not so efficient a means for power transmission as one running a moderate speed, it became evident that there was not so much want of accuracy in the figures given in the paper, or any tendency to condemn without good reason what had satisfied them all till they had learned of something better. What had evidently been entirely overlooked by the crane-makers who had spoken was the relation between the power required to drive a rope for a crane, and the power that could be obtained from that at the speed it was being driven, or, as he had called it, the capacity of the rope. The apparent discrepancy between the figures mentioned by Mr. Jenkins and those quoted from Mr. Barr's paper, and also those obtained from their own cranes, might, therefore, be very easily explained by the difference in the size of the ropes and the speeds they ran. The capacity of the crane mentioned by Mr. Jenkins was evidently 13 tons, lifted 3ft. 4in. per minute, or say barely 3 HP net work done, and then it was working according to Mr. Jenkins at 30 per cent. over its rated power. It would readily be seen that to increase this capacity to what was now usually expected would necessitate more power being wasted on either a larger rope or an increased speed, and this would bring the power absorbed per hundred feet length of shop nearer to his figures.

It was, however, in comparing the complete results of Mr. Jenkins' tests that the great difference between his crane and a three-motor crane became apparent. By dividing the net work done in the experiment by the indicated HP absorbed at the engine, the efficiency was found to be only about 9 per cent., while with the three-motor crane the efficiency under similar

conditions would be 30 to 40 per cent., and these figures only apply during the actual operations of hoisting, &c.

If, however, it is assumed that the crane works one-tenth of the whole time the engine was running, this being a generous estimate, the efficiency fell to the absurd amount of one per cent., whereas with an electric three-motor crane, driven from the main leads, there was, of course, no power wasted while the crane was idle between the operations.

As already stated, it was in the intervals of rest that the great advantage of electric driving came in, and for such work as driving travelling cranes made it the most efficient method yet available.

As to Mr. Dixon's enquiry with regard to the best voltage to adopt, this was a matter that depended largely on circumstances. The tendency seemed to be towards increasing it now that greater reliability could be placed on the apparatus, owing to the very excellent workmanship now carried out by first-class firms. The advantage of the increased voltage was that the conductors were proportionately reduced in weight and cost.

Replying to Mr. Simpson, he had not intended to advocate the adoption of electric driving under all circumstances yet, but had merely pointed out what he knew had been done, and the reasons for still further development.

As to electric travelling cranes *versus* other types, he must unhesitatingly assert that electric cranes of a suitable type had only to be known to be adopted in preference to every other kind yet on the market. The gearing used throughout the cranes mentioned by the author was spur gear, and the bulk of the gears had machine-cut teeth, hence the high efficiency.

Mr. Renold had suggested chains as suitable media for transmission between dynamos or motors and shafting, but he did not mention the efficiency of such a method, and the author's

opinion was that direct coupled engines and dynamos were up to now the better arrangement.

The author's thanks were due to Mr. Nicholls for pointing out in his communication the electrician's objections to reversing motors, but the author could assure his readers that none of the four objections mentioned had any practical value. This could be demonstrated to any of them who could take the trouble or spare the time to visit their works at Hyde. He quite agreed with Mr. Nicholls that it was desirable to have separate generators for lighting and power, but it was not essential. They had worked the past two winters with only one generator, although the lighting load alone was about one-half the capacity of the plant and the total motor load was about six times the balance, and was made up of reversible motors that were constantly stopping and starting. There was, of course, some fluctuation in the lights, and, as stated in the paper, they were building a larger generator to take the power load. They would then have a separate plant for each description.

He quite agreed with Mr. Nicholls as to the advantage in the polyphase system of dispensing with the commutator, and, as mentioned in the paper, the bulk of the power transmission at East Pittsburgh was on this system, although they had direct current available if they had preferred it. The whole of the advantages were not, however, on the side of this system, the direct current having much in its favour, to mention first the uncertainty of the patents held under the polyphase system. To come, however, to practical matters in connection with this branch of the subject, it was quite possible to make direct current motors that would run "for weeks" without attention, although they, equally with those of the polyphase variety, were all the better for receiving a little supervision. The commutators of direct current machines was a matter that too

much was made of in some quarters where, evidently, extreme cases were taken as samples.

The very fixity of the speed was often a disadvantage, as in the case mentioned by Mr. Dixon, where eight different speeds were required in one instance, and this was by no means an uncommon requirement for driving machine tools. The starting torque of a polyphase motor was no doubt sufficient for such purposes as it had been applied to, but to get a high starting torque the current must be proportionately high, whereas with a direct current series-wound motor the starting torque increases faster than the current. In this connection he had noticed that at East Pittsburgh the lifts, which were driven like the rest of the factory from Tesla motors, were driven by belts from motors kept constantly running.

In conclusion, the author thanked all the speakers who had joined in the discussion for the opportunity it had afforded him of speaking more fully on the points raised.

ON THE DEVELOPMENT OF THE MILLING MACHINE FOR HEAVY ENGINEERING WORK

READ SATURDAY, 28TH MARCH, 1896,

BY

Mr. SAMUEL DIXON, M.I.Mech.E.,

(PAST PRESIDENT OF THE ASSOCIATION.)

In entering upon the consideration of this question, perhaps the greatest difficulty one feels, is to determine where to begin and how much to assume, for there is such an abundance of material that it is impossible within the limits of an ordinary paper to go over the whole ground.

My object in preparing this paper is to review, in some measure, the rapid development of milling which has taken place in recent years in all the best engineering workshops, and endeavour to point out the broad lines upon which the development is taking place.

Of the great advantage of the milling process over that of the older methods of metal cutting I do not purpose at this point to enter, though it may be desirable, for one cannot help noticing the lingering conservatism of many engineers, who even now look askance on the process of milling, utterly unaware of the great advantages it would confer upon them.

In this respect I would, however, briefly say that I know of no other process in engineering work in which the great advantages have so much to be realised by experience; for where the work is properly entered upon (and it is of great importance to start aright) it is simply astounding how many objects lend

themselves to the process so perfectly, and so much so, that one is tempted to wonder why any other process was ever adopted.

In reviewing the development of milling, it will assist us very much if we bear clearly in mind the great cardinal principle of milling, viz., the employment of a small battalion of cutting edges, each prepared to relieve the other in rapid succession, so as to avoid the fatigue of any single one, as compared with the employment of a single-cutting edge which shall have to bear the whole brunt of the work without any relief, until it is entirely overcome or used up.

It is upon this idea of employing a battalion of cutting edges in the machining of any surface, and how to employ them to the greatest advantage, that the whole element of design in milling machines has turned during the last few years, and so rapid has been this development that a few years ago machines of two or three tons weight were considered heavy milling machines, whilst to-day machines of ten, fifteen, twenty, and even thirty tons weight are becoming common.

Bearing in mind the cardinal principle of milling, let us next see how the employment of this battalion of cutting edges affects the design of machines. We all know that where ten men are employed more space is required for them to work in than if one man was employed, and so with a number of cutting edges in succession. Again, as a matter of geometry, I think it would be quite easy to demonstrate that the best method of getting this battalion of cutting edges to work at any one single point is to let them march round in a circle, each taking up the work in succession, and, having completed it, march round to the rear and prepare after a rest for the next effort.

Perhaps one of the great elements in the problem which has been least easily grasped by machine tool makers, has been the

fact that the conditions under which a battalion of cutting edges can be got to work are very widely different from those of a single point, otherwise one could not account for the many lame designs of milling machines in the market which are only modified slotting and planing machines, and one can hardly suppress a smile as they are produced with all due solemnity as something quite new. One of these, which has amused the writer perhaps more than any other, is a vertical milling machine made by an old-established firm from an old slotting machine pattern. The tables, which have the usual compound and circular motions, are fitted with three independent reversing feed motions, the designer utterly overlooking the fact that only one of these motions can ever be employed at the same time, and that a single reversing motion applied to the first motion feed shaft would have served for all.

We all know that the strains upon a single pointed cutting tool are very simple and can be easily grasped, so that if provision be made for firmly clamping and supporting same, little apprehension need be felt as to its doing its work satisfactorily. In a milling machine, however, the necessity for a free rotary motion of the tools, and at same time the most unyielding support of same, present a problem differing enormously from that of a single tool. Take a single instance in milling machines of the Planing Machine type; how many designs have been prepared which seem to assume that it is only necessary to support the tool longitudinally by uprights of the same form as planing machines, whereas the transverse strains, when edge milling at a great height from the table, soon show how fallacious is such an assumption.

One of the great hindrances to the development of milling has been the existence of many surfaces which were originally designed for machining by a single tool, and on which a battalion could not be employed.

The chief point in this developement has been the design in recent years of machines specially arranged for getting this battalion of cutting edges to work on practically any surface which can be presented.

With reference to the design of surfaces for milling, undoubtedly much can be done when it is fully understood that such surfaces have to be milled. A notable instance of this has been in locomotive connecting or coupling rods where the form has been slightly modified to allow of a complete finish from the milling tools. We must of course bear in mind that there has often been a difficulty for planing machines to get to machine surfaces designed by some freak, which made them almost impossible to machine, and similarly the milling machines have been passing through much the same development as the planing machine was formerly subjected to. This question of care in the design of surfaces is a most important one in the economy of constructions generally, and much could be written upon it, yet it is surprising how frequently engineers neglect it. Machine tool makers get an experience in this direction which is perhaps unique, for every cranky design is sure to get sooner or later to someone who is asked to offer special machines for producing same. It is, however, not often that the maker finds it impossible to offer some machine capable of doing the work asked for, but often he knows that a little greater care in design of an article would enable it to be produced at a greatly reduced cost. In the case of enquiries emanating from a neighbouring firm, any such question can of course be easily dealt with (provided it is from a firm open tc receive a suggestion), but with distant foreign firms one is often compelled to comply with the literal requirement and offer accordingly.

In reviewing the development of this work of machining surfaces by rotary cutters, I do not intend to deal with the production of those extremely small parts belonging to sewing

machines, knitting machines, small arms, &c., where the vast numbers required of any single article render it a comparatively easy matter to design machines and cutters, specially adapted for the one job. What I do wish to emphasise in this paper, is the rapid development of the process to meet the wants of general engineers where it becomes necessary to have machines capable of machining practically any surface on heavy engineering parts, large or small.

To fix our ideas, we may consider all the surfaces on engineering objects apart from the nature of the work to be such as have formerly been machined on one of the following typical machines.

1st. Surfaces finished on Shaping Machines.

2nd. Surfaces finished on Slotting Machines.

3rd. Surfaces finished on Planing Machines, with the object reciprocating.

4th. Surfaces finished on large objects which were fixed and the tool traversed as in Side Planing Machines, Wall Planing Machines, &c.

SURFACES FORMERLY FINISHED ON SHAPING MACHINES.

These are now almost invariably finished on Horizontal Milling Machines with the ordinary spiral cutter where simple flat surfaces are concerned, or with gang cutters where several surfaces can be finished at one cut as in the caps of pedestals and similar objects. In such work there is an enormous saving, for not only is a plain surface finished quicker by milling than by shaping, but where several surfaces have to come together or are required to be uniform in thickness or in width, this uniformity can be ensured with the greatest certainty; whereas, by the older process of shaping, the setting of the tool to every surface and again to every object, introduced such a number of small errors and variations among the objects machined,

that the liberal use of the file and consequent expense was unavoidable.

Take a very simple illustration in such objects as screwing machine dies, which are plain bars of cast steel, machined all over, but which require to be uniform in thickness and in breadth. By the older process of shaping or planing, the cost of machining alone was quite double if not treble that of milling, but even after machining a great difference comes in for slight deviations were always to be found among the dies shaped, and these had to be rectified by filing. By milling, however, these can be produced perfectly uniform both in thickness and breadth, so that in such simple objects as keys for fly wheels, pulleys, &c., uniformity can be attained with the greatest ease.

Again as to the quality of surface, there can be no question that the finish of a surface from milling is far superior in most objects to that of shaping, and is in fact superior to what can be produced even by the shaping machine and file together. Milled surfaces may therefore be regarded as surfaces which are so perfectly finished that they may in many cases be left from the machine. An interesting fact in this connection was mentioned to the writer by a large firm of Sheffield file makers, who said that since the introduction of milling machines they had found a remarkable diminution in the number of files required by engineers using such machines.

In addition to those plain surfaces which can be best milled with the plain spiral cutter, come a large number, in fact the largest number, which can be done by face cutters. These face cutters for comparatively small objects are often made solid, but when made with inserted teeth can be of practically any size. It is this form of cutter which lends itself so admirably to almost every class of work and which is doing so much for the

development of milling. Another great advantage of this cutter with inserted teeth is its comparative cheapness. The weight of steel used in any one cutter is also so small and of such a simple section, that any ordinary workman can make, harden and insert them; and further, seeing that such a small quantity is required in such a simple form, a steel of the very highest quality can be employed, giving the same advantages in milling as are derived from the use of such steel in tool holders for turning, planing, slotting, &c.

There is one erroneous idea to be found occasionally among engineers with respect to milling with which I would like to deal at this point, and that is the supposition that milling is not suitable for general miscellaneous surfaces and is only of advantage where a number of objects have to be made all exactly alike. This idea, I believe, arises from a recollection of the field in which milling first made its mark, namely, among small objects for sewing machines, knitting machines, small arms, &c. For such work, the machines were very special, and had an extremely limited capacity, so much so, that objects with a slight variation in form could not be attempted upon them. To-day, this condition of things is entirely altered, for whilst there must ever remain a large number of special machines only intended and suitable for particular work, there are also machines having a perfectly universal character, ready for machining any surface upon which a little common sense has been expended in the design. It is necessary, therefore, to point out very prominently the fact that the common spiral cutter and the face milling cutter, with either solid or inserted teeth, are together capable of machining almost any surface whatever.

The only thing required is a machine so constructed as to be able to quickly present one or other of these cutters to the surface requiring machining, and, at the same time, to be able to

support these cutters in such a manner as to get the maximum amount of work out of same.

With small objects formerly shaped it is usually the object which is adjusted and brought up to the cutter, in fact, the reverse of shaping, but in large objects it is usually the cutter which is traversed and adjusted.

Next let us consider the second case, or the

WORK FORMERLY DONE UPON SLOTTING MACHINES.

The gain in the adoption of milling in this work is perhaps the greatest in the whole range of engineering workshop practice. For the operations of key grooving and the machining of few extremely odd (often badly designed) surfaces, the slotting machine will perhaps ever be necessary, but as a machine for producing finished surfaces in the wider sense its use may be regarded as becoming rapidly obsolete. Not only is the work done quicker on the milling machine, but the work when finished is infinitely superior to that from the slotting machine, so that the saving of fitter's time formerly expended on adjusting and draw-filing is very great; in fact, the work of the fitter will in the near future be almost entirely confined to setting out work and assembling the parts after they have been finished on the machines. This undoubtedly is what should be the case, for looking at the matter broadly, the fitters are simply men who in the past have been almost entirely occupied in correcting by hand labour the imperfections left in the work by the machines.

Where a vast proportion of fitters are employed you may draw a very fair conclusion that the work turned off by the machines is far from perfect. One well remembers the day when the fitters were set to chip over by hammer and chisel numerous surfaces which could not well be machined, and some years ago I came across a slide lathe bed, about 10ft. long and some 18in.

wide, which had been chipped and filed from end to end. It was a beautiful job, yet it left the unpleasant impression on one's mind that the man was possessed of a much greater amount of muscle than brain.

Whether we shall ever arrive at that stage of perfection when hand work shall be abolished in the production of all ordinary surfaces it is impossible to foretell, but with the introduction of milling it is tending very rapidly to this, and this ideal of constructive work may now very fairly be regarded as within measurable distance.

Of all the tools in an engineer's shop the vertical milling machine of the slotting machine type is perhaps the best, and as showing what I refer to, I have selected photo Plate I. as a type of this family of machines. From the photo it will be seen that whilst the cutter is very firmly supported both above and below, it is driven by a strong spindle and spur gearing. The circular table is provided with all adjustments and self-acting feeds, so that work can be rapidly mounted and brought to the cutter, much in the same way as in slotting machines. An interesting point about the driving is that spur wheels only are employed which can be entirely suppressed, and the belt alone used for finishing with light cuts or for brass work. Where bevel gears are used for driving it should be noted that these can never be suppressed. The spindle of the machine selected as a a type is 5in. diameter in the body and much larger in the front bearing, and being carried in conical bearings, forms an efficient driver to the mandrill, without torsion and consequent vibration. A special feature in all these machines is that the feed motions are entirely independent of the driving of the spindle, so that the speed of the spindle can be varied to suit the different diameters of the cutters without varying the rate of traverse, hence the amount of metal cut away by any individual tooth of a cutter remains the same whatever the diameter of the cutter.

It will be noticed also that the feed motion is positive and not dependent on any frictional device after the strap, so that once the rate of feed as given on the index attached to the machine is fixed, a uniform traverse can be relied upon. This is a matter of great importance where a smooth uniform surface is required, for should the feed slip so that an additional number of revolutions of the cutter are taken in any one spot, a line or mark is certainly left upon the work.

Circular Milling.—These machines, are before all others, the type for use where all such objects, as cranks, levers, &c., with circular ends have to be machined, but there is a wide field open for completely milling circular objects more economically than turning, even carrying the idea as far as milling the edges and faces of pulleys and similar objects at the same time.

Profile Milling.—This type of machine also lends itself well to profiling or the milling of objects of irregular form such as cams, levers, &c. For this purpose, the table is left free to slide longitudinally, so that a template of the same shape placed under the work determines the advance or withdrawal of the work as it passes before the cutter during the action of the transverse feed. It is of great importance when taking heavy cuts to have a bearing for the lower end of the mandril, yet it is surprising how much can be done on such a machine without any support; in fact, I have seen cutters being effectively used even 9in. long and not more than 1¼in. diameter without any support whatever. For general engineers, the question of profile milling is only of secondary interest, seeing that good designers almost invariably succeed in working out all their forms as combinations of straight lines and circles, so that fancy ogees and similar forms of a costly character are practically abandoned. This type of machine, which for purposes of distinction one feels sorely tempted to name the Slotto-milling Machine, is also capable of doing an immense amount of work with face milling

cutters quite apart from its general work as an edge miller. Such work was formerly done on shaping machines, so that using face as well as spiral cutters, objects can be milled on the top and all four sides at one setting. This is a point of much importance and often overlooked by engineers, who usually regard its function as one of edge milling only.

Profile Milling of long objects.—For profile milling of long objects such as connecting rods, coupling rods, levers, &c., where it is inconvenient (owing to their length) to swing them about for the finishing of the curved ends on the slotto-milling machine, the machine shown on Plate II. is a well recognised type where the object is mounted on a long table with a longitudinal feed motion, the cutter being carried by a vertical spindle on a sliding saddle. The transverse motion of the spindle is controlled by a template of the same form as the object and lying alongside it on the table. Though geometrically speaking these movements allow of almost any form of object being milled, yet owing to the sustained effort and attention required when going round sharp or difficult curves it is only by experienced workmen possessing the highest skill that perfectly satisfactory work can be produced, hence the advantage of so simplifying the designs of objects, as to bring them within the range of straight lines and circles.

We now come to the very interesting group of

MACHINES FOR DOING WORK FORMERLY DONE ON PLANING MACHINES,

and from their similarity in outlines and function are now known as plano-milling machines. These are usually of the horizontal type as shown in Plate III., or of a combined vertical and horizontal type as shown in Plates. IV and V., known as Universal Plano-milling Machines.

The horizontal machines are of various sizes but the one shewn on Plate III. may be regarded as a type and is a very powerful one. This though designed originally for milling over

the heavy steel slabs forming the armature of dynamos, also serves admirably for machining long flat objects of a slab like form such as connecting rods, levers, coupling rods, sides, and sweeps of cranks, &c. This machine is capable of taking a cut 24in. wide, the cutter shewn on the machine being 24in. long and 6in. diameter. The adjustments for rapidly bringing the work to the cutter and returning the table are by power as well as by hand, so that a series of pieces can be changed behind the cutter without stopping the work.

It has always been a moot point with the writer whether the design of the common planing machine has not been on wrong lines from the very beginning, for to reciprocate a heavy table say of 10 to 15 tons weight, or a total with load of 20 to 30 tons at speeds varying from 20 to 50 ft. per minute, absorbs such an enormous amount of power, besides requiring double the length of shoproom. In milling machines, this rapid reciprocation of heavy pieces is entirely dispensed with, and another very great advantage thereby comes into play.

It is well known among all engineers who have gone carefully into the matter that quite one-third of a man's time, and also that of the producing capacity of many valuable machines, is lost in the setting of work.

In planing machines this is quite unavoidable, as nothing can be set on the table when in motion, and the difficulty can only be mitigated by the man having two machines, so that one is often working whilst the other is stopped for setting. It is at this point where a great advantage in milling comes in, for the movement of the table is so slow that, by having the machine sufficiently long, a second object can often be set ready whilst the other is being machined. The man and the machine can therefore be continuously occupied, so that a saving of about one-third the producing capacity of a machine can often be effected from this circumstance alone, quite apart

from the gain arising from the use of a battalion of cutting edges as compared with that of a single point.

The driving of the large cutter, or its articulation as the French would say, with the spindle may be of interest, as it is one which the writer designed and adopted many years ago, and which has now been flatteringly adopted by some of the best English and even American firms. This is shown on Fig. A, Plate VI.

From the drawing it will be seen that the spindle nose is coned out to receive the solid end of the cutter or mandrel. This ensures that the cutter or mandrel shall run perfectly true, but no attempt is made to rely on the friction of the cone for driving. Across the end of the spindle nose will be noticed a groove, and on the shank of the solid cutters or mandrels two flats are formed, so that when the mandrel is inserted it forms a perfectly solid drive by the two flats, absolutely independent of any frictional device whatever. The spindle is bored through, so that the mandrel or cutter is held by a screw from the end. It can also be held by a cap screwed on the spindle nose, but is not so good, as the screw serves to drive out the mandrel when necessary. Fig. B shows the same driving applied to a cutter head with inserted teeth.

An interesting application of milling is shown in Fig. C, where one of the large horizontal milling machines is being used for milling the curved ends of the sweeps of cranks. Every engineer will be able to appreciate the value of a tool which can machine these surfaces in a fourth of the time without having to swing them round in the lathe, always more or less unbalanced and at the best a very slow job.

It will be seen that all that is necessary is to mount the crank on parallel V blocks, and mill right across them with a curved cutter as shown.

The machines shown on Plates IV. and V. are types of machines suited for a very wide range of work formerly done on the planing machines. The vertical spindles, of course, serve for either edge or face milling cutters, but when the saddles are fitted with the pivoting horizontal spindle, seen on photo Plate IV., the machines become for the time universal plano-milling machines.

The useful character of this pivoting horizontal spindle can best be seen from the diagram shown on Fig. D, which is a plan showing how the face cutter may be set to operate on any four of the vertical faces of the object, by traversing either longitudinally or transversly. There is an immense variety of objects which can be also milled which are too large to pass between the uprights of the machine. These can be fixed on the table in front of the cross-slide, and the horizontal spindle used with a face milling cutter as in Fig. E, which shows this spindle operating upon the steam chest flanges, and in the same manner can be used for milling out the ports by using the transverse feed motion.

Plate V. shows the same type of machine with two saddles on the cross slide, each carrying a spindle, in fact these Universal Plano-milling Machines are now constructed of any size with either one or two saddles carrying spindles on the cross slide, just as with the tool boxes of planing machines.

Circular Milling Machines.—For the milling of many objects formerly done on the chuck lathe, horizontal turning mill, &c., circular milling machines present many advantages, and Plate VII. may be taken as a type, though as shown it represents a special form adapted for milling round the flanges of cylinders, valve chests, &c., and is provided also with a radial drilling arm on the cross slide for drilling and tapping the stud holes when so set for milling. The machine shown in this photo admits objects up to 7ft. 6in. diameter and so much as 8ft. 6in. in height. When milling at such a height from the table it

will be readily seen that provision has to be made for resisting strains of a totally different kind to those met with in planing machines, so that to ensure perfect rigidity the uprights for carrying the cross slide are provided with transverse wings, and not merely the common form of upright usually found in planing machines.

The rapid adjustment of the work to the tool, and also for the raising and lowering of the cross slide, as well as the traversing of the saddles on the cross slide, quick power motions are provided, in addition to the series of graduated speeds for feeding up the work when milling.

MILLING MACHINES FOR LARGE FIXED OBJECTS.

The necessity for these has sprung up just as did that for wall or side planing machines. In one important feature however they differ, for seeing that powerful machines with strong spindles having longitudinal, vertical and transverse adjustments are necessary for milling, it requires but a slight addition to make the same machines into perfect boring, drilling, tapping and studding machines. This combination it will be seen has many advantages, for when an object is once set all the surfaces in most cases can be milled over, and the holes in same bored, drilled or tapped as the case may be. The economy arising therefrom is very great in heavy work where operations are comparatively short when once set, but where the cost of handling and setting on different machines is often very great. This is only another illustration of the modern tendency of all good machine design, to eliminate as far as possible the great cost of setting work accurately on machines.

The machines shown on Plates VIII. and IX. are typical of this class of machine, which are made in several sizes, the largest covering surfaces up to 30ft. long and 10ft. high, and not only for milling over these surfaces, but also for boring,

drilling, tapping, and inserting studs in any part of these surfaces. The machines shown on photos No. VIII. and No. IX. may be taken as types of these large boring and milling machines, the smaller one having a spindle 4in. in diameter, and the larger one of 6in. diameter.

In addition to the large milling head which can be used on the horizontal spindle an extremely useful milling or boring head with a transverse spindle can be attached. It will be noted that this is mounted on a circular base, so that this spindle can be used vertically, horizontally, or set round to any angle as in the universal plano-milling machine shewn on Fig. D, Plate VI. It would not be of any advantage to describe all the details of the various motions which it is necessary that such machines should be provided with, but these machines having now grown beyond the range of simple hand adjustment are furnished with rapid power adjustments in every direction. They are well within the range of the workman and under such perfect control that only very slight adjustments for sizing and fine setting are ever required by hand.

Returning once more to the general question of milling, it will, I think, be conceded after carefully comparing the capacities of this series of machines which I have selected as types, that the whole range of engineering work is now well covered by same; not that every cranky surface which an inexperienced draughtsman may have designed can be milled, but I am well within the mark to say that there is now no reason why almost all surfaces should not be brought within the range of the milling machine, especially if in designing the few simple requirements of milling be kept well in mind. At this point I may say that machine tool makers themselves have had perhaps more difficulties to contend with than other branches of engineering, considering the numerous angles of slides and the immense number of T slots which are to be found about every

machine; yet these difficulties are rapidly disappearing, and will very soon cease to exist.

In treating thus fully the broad features of milling I would not be understood to imply that planing machines will be put out of use in engineering workshops; but, considering the great advantages of milling, does it not behove engineers to consider more carefully whether in the classification of their work for economical production a very much greater share shall not be allotted to the milling machine?

Before concluding I would like to direct attention to the great necessity for accuracy which exists in this group of machine tools, above all others, as well as thoroughness in the design of all details. Engineers are, of course, well aware that a high degree of accuracy of production can only be obtained from machines which in themselves are accurate, but apart from this I do feel that the introduction of the system of milling in itself has been an immense advance towards that great goal of ideal perfection.

To-day, machine tools are the parents of all mechanical forms, hand labour counting for little; and just as in the animal world an imperfect creature goes on reproducing its kind with all the natural defects of the parent, so too, in the mechanical world, inherent imperfections in our machines can only result in defects in production.

In conclusion, gentlemen, let me say that my object in preparing this paper has not been so much to present the novel features of any particular type of milling machine, but to emphasize what I consider to be two important advantages, which would arise from a more extended use of milling machines, viz.: increased economy of production and increased accuracy or higher quality of the work produced.

The former of these, *increased economy of production*, is a point which appeals to engineers of every class, and I rejoice to

think that the latter, or *increased accuracy of production*, is a matter which is daily becoming more appreciated by engineers throughout the world, but in Manchester where the influence of that great father of mechanical accuracy, *Whitworth*, will ever remain, I need make no appeal to Lancashire engineers to give the latter of these considerations its full value.

DISCUSSION.

Mr. THOMAS DANIELS asked the author whether he would recommend special tools for special work, or the universal tools. He referred particularly to locomotive work. In the universal machines it appeared to him that two-thirds of the machine was not in use. From what he could see, a large proportion of the work in engineers' shops could be done by milling machines, but he could not see at present that the milling machine would be better than a modern planing machine for engine beds, hammer blocks, and large pieces of work that belong to large stationary and marine engines.

With regard to planing machines cutting both ways, many would remember Whitworth's "Jim Crow" motion, in which the tool reversed.

It was very necessary to have good machinemen to work the large machines. He made it a rule to have boys as apprentices to machines just as they had apprentices to lathes and other branches of the trade—by doing this he obtained the best results from the machines.

Mr. HANS RENOLD said he would have liked to hear more about the construction of the cutters used in milling machines, as this was, to his mind, a far more important question than that of the machines themselves. They might do good work with a good cutter and a badly designed machine, but they

could not do good work with a bad cutter, however good the machine itself might be. With regard to driving the cutter, he did not believe in the cone-bearing adopted by the author; a parallel bearing was the best. Milling would, no doubt, in the future become a general operation in engineering works.

Mr. ALFRED SAXON said he had often thought that our existing tools had not been improved and developed to the extent that was possible. It was a well-known fact that in several large workshops attempts had been made to utilise, in planing machines, both the forward and return strokes. He had no doubt that if as much care were taken in connection with planing machines as was necessary with milling cutters (if they were to be worked to the best advantage), the former class of machines would be a more efficient tool now than was actually the case. The difficulty was to obtain men who could adjust the tools in such a manner as to utilise the forward and the return stroke, and in this direction, the planing machine might be much more fully developed than it was at the present time.

The slotting machine also, he contended, had not been used to the best advantage. In large work especially, there was a large gain in using two tool-holders, and utilising the return stroke. Undoubtedly, both the planing machine and the slotting machine could be used in their return strokes, with no more trouble than had to be taken to use a milling machine to the best advantage.

The author was making milling machines, but it would be interesting to learn if he was using them in his own works, and had sent all the planing machines, &c,, away.

(Mr. DIXON said his firm were using milling machines very largely, but had not yet completed their changes in the above direction.)

Mr. SAXON, continuing, said he would like to have the author's opinion as to whether, in cases where there was only a limited number of machines, the system of milling had advanced so far beyond the experimental stage that it would be advisable to entirely dispense with their existing machines and replace them with milling machines; or was it better at first, to obtain only a machine of one or other of the types described and so educate the workmen gradually to the new system.

Despite the author's remarks about designing, they must not forget that in general engineering shops they could not secure exactly their own choice of designs to the extent the author had indicated as possible. After all, when they had workmen who were accustomed to using general tools, and work was required which could not be done without a special design of machine, if milling was used, the question arose as to whether they must go in for a machine which would be stopped for a great portion of the time. The author had not alluded to the comparative cost of milling machines as against that of slotting or planing machines of the same type and size.

Although the author had said he did not think the ordinary tools would be dispensed with, he seemed to think that anyone who had not already adopted the milling system was very much behindhand. No doubt it was very useful in large engineering workshops, and where work was not required in a hurry, but in shops like the speaker's, where breakdown work was frequently being done, it would be very awkward if they had to make a milling cutter to do it.

He, however, gathered that the author recommended them to gradually take up the system, and this might, no doubt, be done in many of their works where it had not yet been adopted.

Mr. ALFRED MUIR said he had in his place a milling machine made in 1851, which had not been beaten yet as regards utility.

He had, in 1877, persuaded Mr. Adams, of the Great Eastern Railway, to have a milling machine, and that gentleman was the first person who had a milling machine to do locomotive work, and it acted very well. Mr. Webb, of Crewe, afterwards adopted a similar machine. A milling machine was a universal joiner, and the larger the surface the more benefit was secured by adopting milling. With regard to breakdown work, he thought if Mr. Saxon got a milling machine into his shop he would soon be desirous of obtaining another.

Mr. HENRY WEBB said the author had given him the impression that a milling machine was far better than a slotting machine for most purposes, and he (Mr. Webb) would like to know whether it would be suitable for slotting large slab cranks for mill engines, say 12in. thick and 3ft. centres. It seemed to him that it would be very difficult to surpass the work done by a slotting machine in this direction by using a milling cutter. At what speed would a cutter work upon a forging of that description?

Mr. W. H. BEASTOW (of the firm of Messrs. Brooks & Doxey) said that his experience of the milling machine was that it was not a new engineering tool, as a many might be led to suppose, but was simply the re-introduction of a once neglected, yet most valuable tool, that could be placed in the engineering workshop. He considered that great praise was due to a many of the great American engineers for their forwarding special machines for the production of milling cutters at such a price as to bring milling to the front as a commercial machine, and not only the milling but wheel-cutting machine also. He said that when employed by the firm of John Glasgow, Government Iron Works, Manchester, they had a milling machine made by John George Bodmer, Chorlton Street, Manchester, about 1824, and

it was in every particular a similar machine that was being made to-day under the title of the "American Universal Miller." It consisted of a 12in. geared lathe headstock, some 2ft. 6in. long × 18in. × 30in. deep, mounted on a box bed with V slides attached to front of box bed, on which was a rising and falling table with horizontal and transverse slides, actuated by feed rod and knuckle joints, the feed motion being obtained from tail pin end, driven by speed pulley driving and bevel gear.

It was between the years 1824 to 1849 that Mr. J. G. Bodmer had several patents granted to him for cotton machines, also for engineering tools, and he rather thought the geometrical lathe and milling machine were among them. The reason this machine was neglected was on account of the cost of cutters, which, at that time, were all cut out by hand. He had at the present time over 160 milling machines of different kinds, varying in weight from 10 tons to about 2 cwt. If asked his opinion with regard to milling, he should certainly say that the milling machine had at last gained a firmer position in the machine shop than it had in the engineering shop, but he considered that the slotting and planing machine would always hold their own place in the engineering workshop, and would never be entirely replaced by the milling machine.

There was no doubt, as Mr. Saxon said, that the planing machine had been neglected, and our tool makers were satisfied to let well alone; but it must not be forgotten that the Whitworth Jim Crow planing machines cuts on both front and back traverse of table. He also remembered some 33 years ago making some planing machines for Messrs. Beaty's, Engineers, of London, with double uprights to each machine for the same purpose. Then again Kershaw & Sons, of Store Street, Manchester, patented a very simple appliance which could be fixed to every ordinary machine, thereby doubling the output by simply altering the reverse gearing and attaching their applica-

tion to the tool box slides. He found from a many years' experience that the machine called a Universal milling machine could not hold its own against the special milling machines that had been and were daily being placed in some of the best managed machine works. In his opinion it was only by the application of chucks, jigs and special cramping arrangement where a great number of articles could be operated upon at once, that they were able to hold their own against the world's competition. Under the above conditions he thought that the milling machines were the machines of to-day, but they would never excel or displace the planing and slotting machine, which he thought would always retain their position in the English engineering workshops.

Mr. HANS RENOLD expressed the opinion that standard machines were the proper ones to use, and he did not approve of every man wanting his own special machine made, according to his own ideas, for every little operation, instead of trusting to the maker's larger experience and better judgment.

The PRESIDENT supported Mr. Renold's remarks, observing that in textile machinery he had noticed that machinists, when they had a large number of special articles to deal with made the mistake of endeavouring to meet the requirements of every special article by making a specially-shaped tool to deal with it. Why should there be such a change in form and design of a tool for milling one thing when there was already a machine for doing practically the same operation? It was more a question of chucks than of the machine itself, and for practically the same work, what he considered faddy departures from the standard design of machine for the operation were frequently made. Was it not common-sense to suppose that large makers, who had had the opportunity of studying the

design of their special class of machine and the conditions under which they worked, would be able to turn out a better machine when left to themselves than could possibly be made when each purchaser insisted upon his own ideas being carried out in the design, instead of accepting the standard design of the manufacturers, evolved from many years' experience. This had struck him particularly in connection with textile machinery.

The reason why the Americans gained an advantage in some markets was not because they had a better grasp of the subject or made better machines, but because they made specialities of their machines, and made them in large numbers of certain types, thus getting the advantage which arose from this system, instead of turning out only one or two of a batch at once as was sometimes done in England. Why was it that a sewing machine could be made at such a low price? The reason was that large numbers were made of the same parts, and it was so in other articles. In machine tools, as in everything else, their American friends were laying themselves out to produce a commercial article cheaply, and it was on that account, and not because of the excellence of their work, that they were finding a footing in many markets in which we used to have practically a monopoly.

With regard to the application of milling, he thought circular milling should be more generally adopted in certain directions. He had seen a plant laid down for making gear wheels at the works of Mr. Hollingworth, Dobcross, in which, instead of turning up wheel blanks, they were milled circularly, and although he could not say whether this answered better than turning, it certainly turned out an admirable job. There was, no doubt, a large scope in this country for the use of milling machines, and if it did nothing else than do away with the large loss of power entailed by moving large masses of

metal to and fro instead of moving a light tool about, as mentioned by the author, it would serve a useful purpose. He thought there was more to be said on behalf of the milling machine than had been said that evening, and he would like to emphasize the fact that the cardinal feature of a good machine was the cutter. Although it was quite true that milling machines for cutting metals were not a new thing, it was not until someone discovered that the secret of the operation was the grinding of the cutter itself to a true circular form that milling became the advantageous process it was to-day.

Mr. J. W. Hulse, in a communication, said: In perusing the paper I find allusion to a milling machine made by an old established firm, from an old slotting machine pattern, the tables of which are fitted with three independent reversing feed motions.

This so resembles the machine designed and patented by my father, Mr. W. W. Hulse (excepting that, though following the slotting machine type, the pattern was a new and specially designed one), that I cannot refrain from making a few remarks in defence of a type of machine—acknowledged in a later part of the paper to be "perhaps the best," and so far appreciated by engineers, that the firm of Hulse & Co. has made a many during the last few years.

One Government Department alone has installed upwards of 30 of these machines, and a similar number has been made for the largest engineering establishment in the north of England.

The advantages of the three independent reversing feed motions are evident enough to those users of machines who value the convenience and time saving to the attendant, in that he need not, with this arrangement, leave his working position, no matter what class of work he may be engaged upon.

Mr. W. H. Beastow proposed a vote of thanks to Mr. Dixon for his valuable paper, which he said, would make them think more of the milling machine than they had previously done.

Mr. A. Saxon seconded the motion, which was carried with acclamation.

Mr. S. Dixon, in responding, said he regretted that the discussion had rather drifted from the actual subject of his paper. He had specially stated that he was dealing with milling machines for heavy engineering work, but the discussion had been rather on special milling machines for sewing machines, textile machines, and small special work. He had particularly avoided that part of the question, as Mr. Lister had previously dealt with it and also with the question of cutters.

With reference to the question asked by Mr. Daniels, he would say that for general engineering works, where the work was extremely varied, the machines of Universal character, such as those described in the paper, were undoubtedly best; where however the work was of a specialized character in quantities, such as for locomotives, textile machinery, gas engines, &c., then special machines can be employed to very great advantage.

It should however be noted that even among general milling machines the capacity and character is very varied, so that in moderate sized workshops two or three prominent types are employed, and the work graded or classified to suit these different types, no attempt being made to do everything on one machine.

This is precisely the same as with planing, shaping and slotting machines. No one machine is expected to do everything.

He had dealt in the paper with machines for large, heavy, general engineering work, and although there was an immense

family of special machines for different classes of work which acted most effectively, yet engineers might have no fear of using the general milling machines and obtaining highly successful results.

He differed entirely with Mr. Renold with regard to friction driving for heavy milling cutters. He had spoken with great respect of driving by this method for small cutters, but for large ones it was utterly useless. They wanted not a small frictional drive, but a positive or solid drive. He congratulated Mr. Renold upon his success in connection with small tools for special work, but such experience was not a sufficient guide for determining the requirements in heavy milling machines.

As to large cutters, Mr. Renold said they could not get them to fit in two places at once, but if they looked at Fig. A, Plate VI., they would see that the solid shank fitted into the cone, and by means of two flats they got a positive drive, combined with accuracy. One or two of the best American firms had adopted this system.

He agreed with Mr. Saxon that the present machines had not been fully developed, but he did not hope in the least they would ever get the planing and slotting machines to work in both directions, for there were practical difficulties which were well nigh insuperable. Of course, the "Jim Crow" was in use in many cases, but in more cases it had been discarded, for there was far "more tuning than playing."

With regard to his question as to existing planing, slotting and shaping machines, he would not consider prudent to discard these, if in good condition, but rather let all future developments be in the direction of milling.

As to comparative cost, milling machines were, no doubt, more expensive than slotting and planing machines of the same size. This was due to having more motions and mechanism,

but better finish and more accuracy were required in every respect, for if not well made they were useless.

With regard to breakdowns, he would like to disabuse Mr. Saxon's mind on one point. He seemed to think that a special cutter was required before any piece of work could be attempted, whereas, for such machines as were described in the paper, just the contrary was the case. If they carefully took type of machine on Plate I. and regarded the cutter as a rotary file, they would simply have to present the work to it. With the ordinary spiral cutter, together with the face cutter, practically any surface could be machined. A fancy-shaped cutter was not needed for such jobs, but simply a reasonable size of cutter for the work, and they could do all that could be effected on a slotting machine, shaping machine, or planing machine, and in much less time.

Mr. Webb had perhaps found the most difficult job possible for a milling machine. The cranks referred to were simply immense slabs, with scarcely any form about them suggestive of what they were intended for, and no doubt slotting in the ordinary way was the best plan to adopt for roughing out, though they might with advantage be finished with a milling machine.

He had seen a magnificent set of milling cutters made by Mr. Bodmer, at Bolton, but that gentleman had failed in respect of the grinding.

The type of machine referred to by Mr. Hulse was not in question, but simply the futile mechanisms by which they were sometimes encumbered, for surely it cannot be seriously contended that a man should be given three levers to fumble with when one can be made to suffice perfectly.

The remarks of Mr. Beastow referred mainly to special machines for cotton machinists, and do not therefore call for any reply; but one question started by him, and referred to by Mr. Renold and the President, is an extremely interesting one,

and that is as to how far engineers should insist on having their own ideas incorporated in the machines they order. In the past this practice has been very prevalent, and in a large measure justified by the fact that machine tool making had not become the very special branch of engineering which it now is.

To-day, however, the special study of machine tools and their capacities for producing high-class work in the most economical manner is a branch of engineering to which many men are devoting their whole lives, so that the experience gained by such men becomes extremely wide and valuable, embracing, as it often does, the best methods employed in engineering work both at home and abroad.

The isolated experience of any one workshop, valuable though it often is, cannot be compared to the wider experience gained by the same problem arising in perhaps 50 different workshops scattered over the world.

In conclusion the author thanked the members for their attention and the appreciation they had expressed of his paper.

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9 Plates follow illustrating this Paper.

UNIV. OF MICH.

UNIV. OF MICH.

Opening Meeting

OF THE

41st Discussion Session.

The Opening Meeting of the 41st Discussion Session took place on Saturday, October 10th, the afternoon being devoted to the inspection of the various Hydraulic and Electrical Installations, Docks, Warehouses, etc., of the Manchester Ship Canal, and afterwards the new Lairages of the Manchester Corporation.

Notwithstanding the inclement weather there was a large attendance. The party, who numbered about 120, were conducted over the docks by Mr. J. K. Bythell, Chairman of the Canal Company, and Mr. W. H. Hunter, the Company's Engineer, who kindly provided steamers for the purpose of visiting the various points of interest. A start was made at Trafford Bridge, and after the Hydraulic and Electrical Installations had been visited, the Warehouses and Transit Sheds were inspected. The party then passed on to Mode Wheel, and afterwards to the Corporation Lairages. At the latter place they were met by Alderman Reade, Chairman of the Markets Committee, who conducted them through the establishment. The party were then conveyed in 'Buses to the Grand Hotel, where tea was served.

Subsequently, the President, Mr. J. Nasmith, in moving a vote of thanks to the Canal Company and the Markets Committee, said that not having been on the Canal for some considerable time, he had had an opportunity of noting the progress made in fitting up the wharves at the docks so that the traffic might be efficiently dealt with. The advance was really enormous. He had never doubted that the Canal must

eventually succeed, and he was now well assured that it had a great future before it. It was imperative, however, that a Manchester line of steamers should be formed, with regular sailings to and from foreign ports. Manchester men, no doubt, would do all that was possible for the Canal, but with shippers and traders some little distance off, such as those of Staffordshire and Yorkshire, the main considerations were to obtain not only cheap transit, but regular freightage for their goods. They must have frequent and dependable sailings. He hoped that ample capital would be forthcoming for the establishment of a regular Manchester line to all parts of the world.

He thought it well—as that was the first meeting, and they had just settled the matter in dispute—to refer to the question of wages. Manchester employers did not at all object to pay a high rate of wages, because a high rate of wages, for one thing, meant improved processes and advancement of manufacture. Their grievance was that under the present condition of affairs, as compared with other districts, Manchester employers were handicapped by a differential rate of wages. They had, for instance, to compete with districts such as Leeds, turning out similar goods, and yet wages in Leeds were 4s. or 5s. less than in Manchester for the same class of work. That, of course, created a difficulty altogether apart from the economic question of high or low wages, and under it the Manchester employer was unfairly handicapped. He did not call in question the rate of wages in the smaller country districts, where the cost of living and similar considerations were a factor, but he justly complained of these differences—to the disadvantage of the Manchester district—in large centres. Certainly, anything that tended to diminish the prosperity of the engineering trade in this district would also have an ill effect on the country generally, and it could not be satisfactory if Manchester was in any sense put at a disadvantage with other towns. He hoped, therefore,

that wages in the other districts would be made to approximate more to the Manchester level.

Mr. T. DANIELS, Past-President, who seconded the resolution, said that undoubtedly there were no better artisans in the trade than those in the Manchester district. As regarded the rate of wages, the employers had agreed to pay the advance, and he supposed they would have to try to obtain work to enable them to pay it. It was of the utmost importance that there should be one uniform rate of wages all over the country, and he hoped that the rate in other districts would be brought up to the Manchester level. That was the only way to maintain a high rate all round, for if Manchester were put into unfair competition they could not expect to always maintain the higher rate. He did not think the wages in the Manchester district were too high. As one of his mechanics said to him, a man who put up a brick wall in a backyard got his 10d. per hour, and yet a working engineer, who had to take care that there was not the most infinitesimal deviation in a piece of costly machinery, had been expected to work for 32s. a week. Manchester manufacturers were known for the excellence of their work, which was greatly due to the excellence of their workmen. But they ought not to be handicapped by the lower wages paid elsewhere, and some effort should be made to put other districts on the level of Manchester. Speaking of the Ship Canal, he readily acknowledged the great benefits it had brought to the district. Formerly Manchester was altogether handicapped against such places as Glasgow, with its river, which gave easy means of shipping to foreign ports. Already the rates for machinery had been brought down from Patricroft to Liverpool, and he hoped better things would follow.

The resolution was unanimously adopted.

The remainder of the evening was spent in social intercourse. Appended is a brief description of the various works.

APPENDIX.

THE Manchester Docks have a total area of water space of 104½ acres, the Dock Quays are 5⅛ miles in length, and are 152 acres in extent.

The dimensions of the various Docks are as follows :—

No. 1	Pomona	...	...	700 feet	×	120 feet.
2	,,	...	...	600 ,,	×	150 ,,
3	,,	...	...	600 ,,	×	150 ,,
4	,,	...	...	560 ,,	×	150 ,,
5	Ordsall	...	...	400 ,,	×	350 ,,
6	Salford	...	...	828 ,,	×	225 ,,
7	,,	...	...	1,177 ,,	×	225 ,,
8	,,	...	...	1,350 ,,	×	250 ,,

The width of the Salford Basin at its maximum is 1,344 feet, decreasing to 300 feet at Mode Wheel Locks.

DOCKS, SHEDS, AND WAREHOUSES.

The Dock premises now include :—

18 Seven-story Warehouses,
7 Four-story Warehouses,
6 Three-story Transit Sheds,
1 Two-story Fruit Shed,
17 One-Story Transit Sheds,
1 Customs Transit Shed,

or a total of 45 permanent structures, besides various temporary Sheds.

DOCK RAILWAYS.

The Dock Railways are about 30 miles in length ; they completely intersect the Dock premises, and are connected with the London and North Western Railway at Weaste, and with the Cheshire Lines Committee's Railways at Cornbrook. The

construction of the new branch of the Lancashire and Yorkshire Railway Company to the Docks is in a forward state.

TRAFFORD ROAD SWING BRIDGE.

MAIN SPAN 129ft. 6in. REAR SPAN 82ft. 8in.
TOTAL LENGTH OVER ALL 211ft. 9in.
HEIGHT OF GIRDERS 30ft.
WIDTH OF ROADWAY 46ft.; CART-WAY 36ft.
DIAMETER OF ROLLER PATH (CENTRES) 59ft. 6in.
NUMBER OF ROLLERS 64.
WEIGHT WHEN SWINGING 1,800 tons.

Constructed by Messrs. John Butler & Co., of Stanningley.

The bridge is worked by two hydraulic engines with independent gear, each being of sufficient power to open or close the bridge under ordinary conditions, but so arranged that they can be worked in conjunction if required. They are of Sir W. G. Armstrong, Mitchell & Co.'s ordinary type, with oscillating cylinders fitted with gun-metal plungers, gun-metal working and reversing valves, and oscillating joints.

The bridge is turned by a cast steel rack fitted to the annular girder above the upper roller path. A central hydraulic ram 4ft. 10in. in diameter is provided, fitted with plunger and fixed to a cast iron bearing plate under the transverse girders of the bridge.

During the operation of swinging one half of the weight of the bridge is taken by the central ram, reducing the load upon the rollers to 900 tons. The weight on the rollers is thus brought down to the initial load of 800lbs. per lineal inch, the standard adopted for the whole of the rollers of the Swing Bridges throughout the Canal.

Hydraulic gear for lifting and blocking the ends of the bridge, together with a locking bolt and disengaging gear are also provided.

The movements of the bridge are arranged so as to be under the control of one valve man in the central cabin.

HYDRAULIC INSTALLATION, TRAFFORD ROAD.

The machinery comprises two pumping engines, two boilers, tanks, feed apparatus, accumulator with pipes, valves and accessories, constructed by Sir W. G. Armstrong, Mitchell & Co.

The two steam pumping engines are of the horizontal compound jet condensing type, each indicating 180 HP and discharging 180 gallons of water per minute at a pressure of 700 per square inch.

The principal dimensions of the engines are $\frac{15\text{in.}+27\text{in.}}{20\text{in.}}$

The high-pressure cylinder is fitted with double slide expansion valves, the normal rate of expansion with a steam pressure of 90lbs. to the square inch is about nine volumes.

The Boilers are Galloway's Patent Type, 6ft. 6in. in diameter and 26ft. long, with a working pressure of 100lbs. per square inch.

A Green's Fuel Economiser with 112 pipes is attached.

The plunger of the accumulator is 20in. in diameter and 23ft. 6in. stroke.

ELECTRIC LIGHT INSTALLATION, TRAFFORD ROAD.

The Steam Engines for this Installation are as follows:—

(1) Two 100 B. HP Engines, by Mr. B. Goodfellow, of the vertical compound inverted cylinder type, $\frac{11\text{in.}+21\text{in.}}{14\text{in.}}$ running 170 revolutions per minute, with a boiler pressure of 100lbs. to the square inch. Both cylinders are steam jacketted, and each engine fitted with ejector condensers. Guaranteed consumption, 20lbs. of steam per B. HP. A fly pulley 8ft. 10in. in diameter, grooved for eight ropes 1in. in diameter, is placed between the cylinders.

These engines drive two 60 Kilowat Alternators and two Exciters (made by the Edison-Swan Company and supplied by

Messrs. Baxendale & Co.), as well as the line shafting and the centrifugal pumps for condensing purposes.

(2) Two 80 B HP Engines, by Messrs. Browett, Lindley & Co., of the vertical compound inverted cylinder type, $\frac{7\text{in.}+11\text{in.}}{8\text{in.}}$, running 250 revolutions per minute, with a boiler pressure of 100lbs. to the square inch, and a guaranteed consumption of 25lbs. of steam per B. HP. Both engines are fitted with ejector condensers, and drive two 18·9 units continuous current dynamos, supplied by Messrs. Royce & Co.

Both sets of engines are arranged for working either condensing or non-condensing, and are capable of exercising their respective powers when non-condensing.

One of Galloway's patent boilers, 26ft. long and 8ft. in diameter, working at a pressure of 100lbs. to the square inch, was added to the existing boilers in connection with the hydraulic installation at Trafford Road, for the purpose of supplying the extra steam power required.

The area lighted includes the whole of the Dock Quays and Sheds, and the Mode Wheel Locks; the lights are as follows:—

66	Continuous current Arc Lamps	all 2,000 C. P.
28	Alternating Arc Lamps	each.
360	Incandescent Lamps of 50 C. P.	each.
100	,, ,, 32	,,
28	,, ,, 16	,,

Only incandescent lamps are used in the Dock Sheds.

RAILWAY SWING BRIDGE.

Main Span 120ft. 3½in. Rear Span 58ft.

Total Length of swinging portion 178ft.

Depth of Girder in centre 22ft. 6in.

Weight when swinging 250 tons.

Constructed by Messrs. John Butler & Co., of Stanningley.

The swinging portion of the bridge is carried upon a central hydraulic press and ram, the latter being 2ft. 10½in. in diameter with 5in. lift.

The bridge is opened and closed by slewing chains working round a drum, which is fixed to the underside of the bridge and worked by two turning cylinders and rams fixed in opposite directions, one for opening and the other for closing the bridge. These rams are 9½in. in diameter and have a stroke of 5ft.

Two cast iron rollers are fixed under the head of the short arm.

The bridge is controlled by one man in charge at the valve cabin.

HYDRAULIC CRANES.

The total number of Hydraulic Cranes at work on the Dock is 88. They were constructed by the following firms:

10 BY SIR W. G. ARMSTRONG, MITCHELL & Co.
10 BY TANNETT, WALKER & Co.
10 BY NASMYTH, WILSON & Co.
4 BY C. & A. MUSKER.
4 BY THE GLENFIELD COMPANY.

The cranes constructed by the three first mentioned firms are capable of lifting 30cwt. through heights of 50ft. and 65ft., the jib having a radius of 35ft.

Those constructed by the two last mentioned firms are capable of lifting 25cwt. through a height of 75ft., the radius of the jib being 33ft.

One movable hydraulic jigger constructed by Sir W. G. Armstrong, Mitchell & Co. has also been provided.

STEAM CRANES.

The steam cranes now at work at the Docks were formerly employed in the construction of the Canal, and comprise:—

5 10-TON CRANES.
2 8-TON CRANES.
7 5-TON CRANES.
27 2½-TON CRANES.

Constructed by Messrs. J. H. Wilson & Co., Mr. Thomas Smith, and Messrs. Pearson & Knowles, Limited. In order to adapt these cranes for traffic purposes, alterations have been made to the gearing, and new jibs of varying length have been provided in the majority of cases, thus enabling them to lift lighter loads at greater speed and radii.

The 30-ton crane was constructed by Messrs. Stothert & Pitt: it was originally intended to be worked by hand, but steam power was afterwards added by Messrs. Nasmyth, Wilson & Co. It is capable of lifting 30 tons to a height of 50ft. from the roadway, and to travel forward a distance of 64ft., so as to bring the load over the hatchway of the ship.

HYDRAULIC JIGGERS IN 3-STORIED TRANSIT SHED.

Four Hydraulic Jiggers, constructed by Tannett, Walker & Co., are provided in each of the six 3-storied Transit Sheds, or a total of 24 in all.

These Jiggers are arranged for lifting loads of 30cwt. and 15cwt. respectively, at a rate of 200ft. per minute, and to travel longitudinally, *i.e.*, in the line of the shed for a distance of 68ft. in each case.

HYDRAULIC CAPSTANS.

Eighteen Hydraulic Capstans, constructed by Sir W. H. Bailey & Co., are fixed at various points on the Dock Quays.

They are of Bailey's four-cylinder type, and are capable of exerting a direct pull of one ton.

GAS ENGINES AND JIGGERS AT THE 7-STORIED WAREHOUSES.

An Otto Gas Engine, constructed by Messrs. Crossley Bros., 14 N. HP is erected in the first block of eight warehouses to work the 16 Jiggers provided therein, and another Otto Gas Engine by the same firm, 10 N. HP, is erected in the second block of five warehouses to work the 10 Jiggers therein.

The Jiggers were constructed by Messrs. Higginbottom and Mannock, and are of the ordinary type for warehouse work.

HYDRAULIC INSTALLATION, MODE WHEEL.

This Installation comprises two complete sets of steam pumping engines, two auxiliary steam pumps, two boilers, fuel economiser, overhead supply tank, accumulator, &c.

The engines, constructed by The Glenfield Co., are of the inverted triple expansion type, jet condensing, with steam jacketted cylinders, $\frac{14\text{in., } 23\text{in., \& } 38\text{in.,}}{24\text{in.}}$ the cranks being placed at an angle of 120° to each other. The fly wheels are 7ft. diameter. The boiler pressure is 160lbs. per square inch. Each engine is fitted with steam starting gear, throttle valve, and governor. An auxiliary starting valve fitted to each intermediate cylinder, and a throttle valve on the main steam pipes near each engine are controlled by the accumulator. Each engine works three single acting ram pumps 6in. in diameter, with a stroke of 24in.

The engines may be worked together or separately, condensing or non-condensing, and each is capable of discharging 20,000 gallons of water per hour, through a 6in. main at a pressure at 700lbs. per square inch, when running at 50 revolutions per minute.

The auxiliary pumps are of the duplex direct acting type, with steam cylinders 8in. diameter, water cylinders 10in. diameter, and stroke 10in. Each pump is capable of lifting from the canal and discharging into the overhead supply tanks, 80,000 gallons of water per hour.

The boilers, constructed by the Oldham Boiler Works Company, are of the two-flued Lancashire type, working at a pressure of 160lbs. per square inch. They are made of steel, 30ft. long by 7ft. 6in. diameter, with flues 3ft. internal diameter, each fitted with five conical tubes.

Two donkey feed pumps by Messrs. F. Pearn and Co. are connected with the overhead supply tank on engine house to the economiser, and by an independent feed connection to the boiler.

All the steam pipes are of steel, solid drawn, with welded flanges. A steam separator—2ft. 6in. diameter and 6ft. high, with steam trap attached—is fixed near the main steam stop valve of each engine.

The fuel economiser is Green's Patent, and consists of 120 tubes 9ft. long, $4\frac{9}{16}$ diameter, in two groups, coupled together with expansion elbows.

The overhead supply tank measures 42ft. × 31ft. and 5ft. 6in. deep, and is supported on girders erected over the engine house.

The plunger of the accumulator, constructed by Sir W. G. Armstrong, Mitchell and Co., is 18in. in diameter, with a stroke of 23ft.

The engines at Mode Wheel and at Trafford Road work into the same hydraulic mains, and the pipes are so arranged that the Locks and Swing Bridges and the Docks may be worked from either place, either separately or together.

Momentum valves are placed at intervals in the mains.

In addition to the hydraulic mains, which are laid in subways round the whole of the quays and jetties of the Salford docks, a water main 4in. in diameter has been laid round the Manchester and Salford docks, as well as on Trafford quay.

FIRE APPLIANCES.

Sets of fire extinguishing apparatus, worked by means of ejectors, which are fixed on the hydraulic mains when required, have been supplied to all the sheds and warehouses. By this means volumes of water from the dock can be thrown on any point or points required throughout the system, and the occurrence of a really large fire rendered most unlikely.

MODE WHEEL LOCKS AND SLUICES.

LARGE LOCK 600ft. LONG × 65ft. WIDE.

SMALL LOCK 350ft. LONG × 45ft. WIDE.

Each lock is provided with three pairs of gates:—upper, intermediate, and lower.

The difference between the level of the Barton pond and that of the docks is 18ft.

The gates are constructed of greenheart timber; their dimensions are as follow:—

	WIDE.	DEEP.	WEIGHT.
LOWER GATES, 65ft. LOCK...	37ft. 3in.	47ft. 3in.	170 tons.
UPPER GATES, 65ft. LOCK...	37ft. 3in.	30ft. 9in.	108 tons.
LOWER GATES, 45ft. LOCK...	26ft. 4in.	44ft. 3in.	85 tons.
UPPER GATES, 45ft. LOCK...	26ft. 4in.	27ft. 9in.	60 tons.

The gates are opened and closed by hydraulic machinery, constructed by Sir W. G. Armstrong and Co., and having a pair of hydraulic cylinders for each gate.

The sluices for working the locks, and also the flood sluices (four in number, each 30ft. wide), are of Stoney's patent Rolling type, and were constructed by Messrs. Ransomes & Rapier.

W. HENRY HUNTER,

Engineer to the Manchester Ship Canal Company.

ENGINEER'S OFFICE,

September 20th, 1896.

General Description of Foreign Animals' Wharf.

OLD TRAFFORD.

The Foreign Animals' Wharf is situated on the South or Old Trafford side of the Manchester Ship Canal, and adjoins the Mode Wheel Dry Dock.

The Ship Canal Railway passes along the south side of the Wharf, to which it is connected by branch lines. A good level road leads from the city, *via* the south approach to the Trafford Bridge. There is a frontage to the Canal of 265 yards, and a

landing stage with three jetties, where the most convenient and approved arrangements for landing cattle have been provided.

The site covers an area of upwards of 12 acres, and is enclosed by a double fence, with an intervening space of 80 feet. This space is to be kept unoccupied, for the purpose of isolating the wharf in accordance with the regulations of the Board of Agriculture.

The Lairs have been erected near to the Canal, and are substantial buildings of brick, with slate and steel roofs. They are divided into compartments, each capable of holding 50 cattle. Each pair of compartments is fitted with brick divisions and sliding doors, for the purpose of isolating the cattle in lots of 100.

The Lairs are well lighted, drained, and ventilated, and are fitted with posts, rails, and feeding troughs. The floors are paved with brick on a concrete foundation. Passages give access for feeding and inspecting the cattle, and have "refuge" gates at each entrance.

An Auction Room, with the usual fittings, is provided at the end of the Lairs, having seating capacity for 140 buyers.

The Cattle Runs are fitted with cast-iron posts and wood cross-rails, with gates opposite the lairage entrances for diverting the cattle in their passage from the ships. The Cattle Runs have side passages, with "refuges" at frequent intervals for the safety of the attendants.

The Pens are placed near to the slaughter houses, and the cattle can be driven direct from any lair to any pen. Two pens are provided for each slaughter house. The Slaughter Houses are of brick and slate, with sliding doors. They are paved with self-faced Rochdale flags, and supplied with water and steam.

The Cooling Room is placed opposite the slaughter houses, and is connected with them by a covered roadway. The room is capable of holding 500 "sides."

Three Chill Rooms are erected on the east side of the cooling room. Each room is capable of chilling 174 sides at a time. The Cooling Tank and Fans are placed over the chill rooms.

The Engine and Boiler Houses stand opposite the chill rooms, and form a rectangular block of buildings 150ft. by 62ft. The chimney is of a somewhat ornamental character, and is 150ft. high. The Boiler House contains three Lancashire boilers, 30ft. long × 7ft. 6in. diameter. Space is provided for three additional boilers of the same size. Feed water is supplied through an economiser. The Engine House contains the engine, compressor, and circulating pump for the refrigerating machinery; the duplex pumps and accumulator for the hydraulic hoists; two 50 HP pumping engines for lifting the whole of the sewage of the wharf to a height of 17ft., and discharging it into the Corporation outfall sewer, which is at a distance of nearly a mile; two 50 HP engines and two dynamos for generating electricity for lighting the premises.

The Storage Batteries are placed in a separate house at the rear of the engine house.

The sewage is collected in two brick tanks, formed at a depth of 26ft. below the surface of the ground. These tanks are immediately behind the engine house to which the suction pipes pass.

Overhead Runners and Rails are fixed in the slaughter houses and continued into the cooling market, where they are augmented by an additional central rail and double rails carrying travelling winches to enable the carcases to be placed on the central rail for immediate despatch. These rails are continued along a covered roadway to the chill rooms.

This building is two stories in height, and is close to the slaughter houses. It is well lighted, drained, and ventilated, and is provided with hydraulic lifts.

Importers' Offices, Men's Mess Room, Kitchen, Lavatories, Bath, Disinfecting Chamber, Public Conveniences, Haysheds,

and other necessary buildings are provided. The Wharfinger's House, with Office and a Committee Room, are placed close to the wharf entrance.

The Roadways and Landing Stage are lighted by arc lamps of 1,200 candle power; the Slaughter Houses, Meat Markets, Chill Rooms, and other buildings by incandescent lamps.

The Corporation have given most careful consideration to the requirements of the trade, and in all details the health, convenience, and comfort of those using the wharf have been studied. Special attention has been paid to the sanitary condition and working of the buildings, and every facility is afforded for cleanliness. The levels of the site with respect to the Ship Canal are most suitable.

The buildings were erected under the supervision of the City Surveyor, in whose department the drawings were prepared.

WATER POWER AND ITS DEVELOPMENT.

READ SATURDAY, 24TH OCTOBER, 1896,

BY

Mr. GEO. T. PARDOE,

(LONDON).

Having been invited by your Council to prepare a paper on "Water-Power" I have very much pleasure in submitting the following for your consideration.

SYNOPSIS.

1. *The sources of water supply, compensation, etc.*
2. *The various motors and their differences discussed.*
3. *Storage, conveyance, and measurement of water.*
4. *A few illustrations.*

The subject of this paper is one which, of late years, has attracted considerable attention, owing mainly to the possibility of transmitting the power developed at any point, to any other point at a reasonable distance, without any considerable loss, and especially owing to the adoption of electric transmission of power in large quantities, and to considerable distances in North America.

The subject has also attracted some attention in this country for the purpose of electric lighting, but it is, however, far too large to be dealt with in a single paper, and the best that the author can hope to do is to form a groundwork for discussion.

It has very often been found that a water-power has not proved to be of the value anticipated, and omitting any question of faulty construction, this is probably consequent upon a hasty adoption of the system. It is seldom the case that the amount of power available can be determined by a single gauging, since the

volume of a stream often varies seasonally between wide limits. A stream which may be worth 500 HP during wet weather may only be equal to 100 HP in a dry season or during frost. A case in point is the Worcester Electricity Works. In spite of careful consideration before the works were undertaken, they have not proved quite so satisfactory as anticipated. From the engineer's report it appears that a large proportion of the total running hours were made by steam alone. This proportion rose to over 75 % about Midsummer, 1895. It may be hoped that this is exceptional, and is only here mentioned to impress the necessity of very careful examination of a proposed water-power.

As, however, it is not usually possible to devote several years to obtaining accurate data as to the qualities of a stream, we are forced to endeavour to seek the necessary information in another direction; and, fortunately, we have two methods available, which, with care, will give sufficient information for our purpose.

1. Where a number of water mills are arranged on a stream, the various millers will be able to give some idea of the variations in the water supply, by means of the various sluice openings and overflows from season to season and year to year, and a comparison of these data with any available data as to the rainfall on the watershed, will enable an engineer to obtain some idea of the proportion of rainfall flowing off, and also to judge of the value of a stream on another part of the same principal watershed where only rainfall data are available. It must, however, be remarked that in this direction great care is necessary in giving due weight to the various local circumstances, such as the character of the ground leading to more or less "absorption," and to the direction in which the watershed faces. For instance, if the prevailing wet wind is south-west, and the stream being considered flows from south to north, then it is obvious that a rain gauge situated on the southern slope

will give less accurate data as regards the stream in question, although on the principal watershed.

2. Another method is to ascertain from a large scale map of the district the area of country drained by the stream in question.

Records of "rainfall" and "run-off" will then enable the engineer to gain an idea of the quantity of water available, and also the ratio between "dry weather" and "flood-flow."

It should be borne in mind that a stream, tributary to a larger one, drains a small district, which may be considered to be its watershed, and that only such data as to "rainfall" and "flow-off" as apply to *that* watershed is of any use in determining the value of the tributary stream. Hence great care is necessary when determining the variations in the water supply, from rainfall measurements obtained by a few scattered gauges.

A further important point which has often to be considered in a thickly-populated country, such as Great Britain, is the relation of the proposed works to others in the district. For example, there is no difficulty, in improperly designed works, of damming back the water to such an extent as to run the risk of backing up the tail water of a mill above, the result of which would probably be legal proceedings. Whilst on the other hand, at a time of short water, a mill owner might easily pond up the stream for the sake of storage, when the mill is not working, in such a way as to deprive the down stream millers of their share of the water, this action affecting the latter in two ways: first, by depriving them of the water they require for storage, and, secondly, the water they *do* get does not reach them as regularly as they are entitled to. Assume, for example, there are two mills five miles apart on one stream, and that the velocity of the stream is two miles per hour, then it is clear that if the up stream miller opens his sluices at 6 a.m. the miller down stream will not feel the "swell" or increase of water supply till 8-30; in other words, he will be unable to

get to full work till after breakfast, the financial effect of which is obvious. The same effect is caused by the action of some water works for town supply, which have the power to give the compensation water to the streams affected, intermittently, instead of continuously.

All these circumstances require to be taken into account when considering the value of a water power, and this can best be done by a number of observations taken over such a long period of time as to practically ensure measurements being made under all conditions of the stream.

As illustrating the great variations of water supply met with, the author may mention measurements of the river Rheidol, made by the Surveyor of Aberystwith in 1893.

In January the flow corresponded to 647 HP.
In April ,, ,, 147 HP,

or a ratio of nearly five to one.

Mountain streams, and those in a rocky country, are subject to greater variations of flow than those in a clay or loamy flat country. The reason is that the latter class of streams are fed by streams more or less deep-seated, which springs are fed by the rainfall soaking into the ground, whilst mountain streams are fed to a large extent by simple drainage from the rocky sides. The rocks not being very porous the rainfall quickly saturates them, and then passes off direct into the stream, whilst the rocks, having small porosity, are able to store but little water and are soon exhausted after the rain has ceased. The result is, the common condition of most mountain streams, viz., dried up, or a mere rill in summer and a bank-high torrent in spring time.

During a tour in North Wales, in the summer of 1895, the author saw a rill of water only a few inches deep after several weeks of dry weather, and on passing it the next morning, after a night of heavy rain, the rill had become a rushing torrent two

or three feet deep, where it had been a few inches the evening before.

Therefore, in mountainous country it is necessary to ascertain the *dry weather* flow as well as the *maximum* flow of a stream, else we may be landed in the position occupied by a firm of electric light contractors, who undertook to light a 150-light house by a two-horse water-power. The lawyers took the profit in that case. The foregoing remarks will show the great need for some means of regulating the flow of streams, especially mountain streams.

If only one stream were affected by the works necessary, and its whole length were under the control of one man, the matter would be simple, but unfortunately our engineering is complicated by works necessary, or thought to be necessary, for the protection of the down stream owners, and as these men cannot always be brought to see reason in the promoter's light, the regulating works at the head are not enabled to regulate the flow to the great nicety otherwise possible.

The ultimate effect of the regulating works should be, in ordinary years, to produce an absolutely uniform flow of the stream controlled, but this is seldom attained and for several reasons :—

1. Because such works are usually undertaken for the purpose of towns' water supply, and being undertaken primarily for that purpose, and not for the improvement of the water-power, the accuracy with which the streams are gauged, and the compensation water calculated, is dependent somewhat on the opposition or otherwise of the riparian owners interested, the result being that in dry weather some streams are almost waterless.

The same result is caused to a less extent by the system of intermittent discharge of compensation water.

2. Because the riparian owners affected, require a greater volume of compensation water than that which the works are

capable of giving, and which, if designed solely to regulate the streams, would obviously be a mean between the dry weather and flood flow.

3. On account of the cost of the works necessary and the improbability of their being effectively utilised. The result is seen in the numerous small storage dams on our lowland watersheds, which merely serve to store the water for one night, partially regulating the flow for 12 hours instead of 12 months.

Water-power development on a large scale usually involves expensive works, and, unless the capital expended can be utilised approximately continuously, the annual cost of a horse-power is largely increased. It is common to hear water-power spoken of as a free gift of nature, but nature, unfortunately, never makes "gifts." Not infrequently, water-power, especially on a small scale, is the most expensive power that can be chosen.

In water-power development, the largest proportion of the annual cost is due to "capital." This part of the annual cost is therefore fixed, and independent of the time of use of the works. A water-power, therefore, which would show a considerable saving over the cost of steam power when worked day and night continuously, might very possibly be much more expensive when worked on a 12-hour day, since the cost per horse-power would then be practically doubled. The result may be then, that storage works to a large extent may pay in the former case and not in the latter, with the further result that steam power must be provided to compensate the fluctuations in the available water-power. Hence steam-power may, on the whole, be cheaper than water-power, especially since with the former we can take the power to the raw material instead of raw material plus coal to the power.

Since manufacturing operations in the present day have to be carried out on a large scale, if they are to pay, water-

power, being more or less limited in this country, is not of as much value as in the past, when such work as woollen mills were conducted on a smaller scale, and the cost of labour was a larger proportion of the total cost than at present. Therefore, such water-power as we have is not conserved or regulated to the extent it might be, with the result that irregular flow is looked upon as necessarily existing in connection with water-power. It must, however, not be forgotten that the land necessary for a compensation reservoir may be of more value *as* land than as the bottom of a reservoir, though this is scarcely likely in the case of mountain sources. Early in the present century, Mr. Thom constructed what is known as the "Shaws" waterworks, near Greenock. Previously, for many years, mills situated on streams in Greenock and the neighbourhood had suffered from periodical droughts, and the local authorities commissioned Mr. Thom to report on the practicability of storing the floods for use in times of drought. The first step taken was to establish "gauges" on the streams and also rain gauges, whilst a survey was also made to determine the area of the gathering ground. The result of the careful collection of the necessary data was, that it was found to be practicable to construct reservoirs of such capacity as to compensate the required streams with almost theoretical perfection, and, in addition, to give a considerably increased supply.

As showing the need of storage, the author may instance the Worcester Electricity Works. The engineer's report for the past year states that over three-fourths of the running hours were by steam, the water being too low for effective use, owing to the very dry winter and spring.

The whole question of water conservation is too large to be dealt with in a paper such as this, but a few remarks are necessary for the sake of completeness.

Assuming a sufficient supply of water, the next point is to consider the class of motor by which the power is to be developed.

The motors may be classified as follows:—

Motor.	Sub-Classes.	Eff. %
1. Water wheels	(1) Undershot	25-35
	(2) Breast	50-60
	(3) Overshot	50-70
	(4) Hurdy Gurdy	40-45
2. Turbines	(1) Impulse	70-80
	(2) Reaction	70-80
3. Simple Impulse Wheels (Barker's Mill).		

In former days, water wheels were the only type of motor available, the idea of the turbine not having been mooted.

Now, it is a common idea that water wheels are entirely out of date, but when we consider their extreme simplicity and durability, the author considers that the owners of many existing mills are well advised in retaining their old friends, notwithstanding the fact that a "Turbine" will often give a slightly larger power from the same water supply.

For example, the author has seen mills in the West of England that have dated from the beginning of the century, and one case, in which a large part of the shafting and gearing was of wood; these old mills seemed to be everlasting.

As to the possible efficiency of a large "overshot" the author some years ago came across an old book on Cornish Mining, in which it was stated that a test of such a wheel about 65ft. diameter, and used for mine drainage, had shown an efficiency of over 60% from water laid on to water delivered in the drainage adit. Assuming a pump efficiency of 80% (which is hardly too low considering the type of valves used and the friction), this shows an efficiency of wheel of over 75%. The pit work was similar to the usual Cornish work.

Again, in the North of England, the author has seen a large water-wheel which had not required any repairs for years. This wheel was between 30 and 40 ft. diameter, and was subjected to heavy vibrations and shocks, the water being led on to it at an excessive velocity, at least half the total head being wasted. It was also erected on made ground, causing heavy vibration.

Another example of a long-lived wheel is that at Laxey, Isle of Man. The diameter of this wheel is 72ft. 6in., and width 6ft., the speed varying slightly with the amount of water available. It is fed by a timber flume, which conveys the water from the hill above, to a masonry tank on one side of a narrow gully in which the wheel is erected. From this tank, the water is conveyed in a pipe up the interior of the masonry column (seen in the photograph), flowing over the top and being discharged on to the wheel through ports in the curb, which, it will be noticed, closely fits the wheel underneath the platform, and Penstock at top. This wheel is used for draining the Great Laxey Mine, the lift being 640 yards, by 5 sets (drawing and forcing) of pumps, the diameter of plungers being about 8½in. and stroke 8½ft.

The pump lever is driven by a crank of 4¼ft. radius on the wheel shaft, being connected thereto by timber rods, strapped with iron and carried by trolleys running on rails on the viaduct, of which the end can be seen in the photograph. This wheel was erected in 1854, and when the author saw it in 1893 it appeared to be practically as good as new. He had no means of judging the water supply with any degree of exactness, so that no figures would be of interest, but it is evident that it would have to be very inefficient to outweigh the small depreciation.

The author is informed that the wheel was strengthened a few years ago at a cost of about £150, and that this is practically all it has cost for repairs since erection.

The horse-power is 200, about.

Breast	6ft. wide.
Revolutions	2½ to 3 per minute.

40 gallons of water lifted per minute.

The wheel has never been required to work full power.

It is commonly believed that a turbine always gives a better efficiency than a water wheel, but this is not necessarily the case. The author is not able to give exact figures as to the efficiency of these large wheels, but is of opinion that for such work as the Laxey wheel performs, the water wheel is at least as good as a turbine if properly designed and built. If a turbine were used the smaller fly-wheel action would probably cause the speed to be much more irregular, whilst a considerable amount of gearing would be required to reduce the speed to a point sufficient for connection to the pump.

When, however, we consider the first cost, the turbine has an enormous advantage.

The author, in using the term "well designed," wishes to draw attention to the fact that the design of an overshot water wheel is susceptible of scientific treatment, just as a turbine, though perhaps not to the same extent. It is not sufficient to pour the water on haphazard, but there is a certain definite relation between the speed of the wheel, the speed at which the water flows out of the chute, and the angle at which the latter is set, and which relation is very easily diagrammatically expressed. The author does not mean to assert that a water wheel will not work at all unless designed on the lines to be set forth, but merely that unless the water is led into the buckets without collision, the energy of the water is spent in producing noise and foam, and by being splashed over the shrouding.

In Plate 1 let E F be a tangent to the surface of the wheel touching the lip of the bucket at A.

On E F set off A B to any scale equal to velocity of circumference of wheel, and from B draw D B parallel to a tangent to lip of bucket. From A lay off A D, making an angle with E F equal to the angle with which the water is laid on to the wheel, then if D is the point at which D B cuts A D, then A D, measured by the same scale as A B, will be the velocity at which the water must be laid on to the wheel in order that it may enter the buckets without shock, and is evidently the component of the velocity of entrance A C and the velocity of wheel A B.

Similarly, if the velocity of wheel and of supply be predetermined, together with the angle at which it is to be laid on, then the correct angle between the tangents to the circumference and the tangent to the bucket lip can be readily determined.

Another method is more convenient when the penstock delivers the water on to the wheel through a number of ports, as for example, the Laxey wheel. See Plate 2.

Let E F be a tangent to the wheel.

Let A be the bucket lip.

From A, set off on line E F, distance A B equal (to any scale), the speed of the wheel circumference.

Set off distance A C, = double A B.

From B draw line B H parallel to a tangent to bucket lip A, and from C erect C D perpendicular to E F, and cutting B H in D. Connect A D.

Then measured on the same scale as A B the line A D will equal the velocity with which the water must flow out of the ports in penstock, in order to avoid "shock," and the angle D A C will equal the angle which the centre line of the port must make with the tangent to the circumference of the wheel.

Similarly, A G, and A I = the velocities of the outflow from other ports, calculated from their depth below the surface of the water in the penstock, and the angles G A C and I A C are equal to the angles of the respective ports.

The foregoing only deals with one point in the design, but there are others just as important.

1. The buckets must be so shaped that whilst allowing free entry for the water, they will retain it to the lowest point possible. If this is properly carried out it will be found that this leads to a very narrow mouth to the bucket, and since the supply ports, from motives of economy, usually occupy nearly the whole breadth of face of the wheel, there is a liability that the air displaced by the inrushing water will cause some of the water to spill.

2. The remedy for this was provided by Sir Wm. Fairbairn, who, in some large iron wheels he built for a Scotch woollen mill, arranged that each bucket should have a ventilating aperture at the back and near the top, so that as the water rushed in the air receded before it. Very little water was lost through the ventilating holes, since they are not required to be large, owing to the much smaller density of air as compared with water.

The small loss may be altogether avoided in some cases by causing one bucket to ventilate into the one above.

A secondary advantage resulted from this, viz. :—

A smaller bucket would suffice for the same power, since the bucket was filled with solid water, and not a foamy mixture of air and water.

Some interesting details of wheel built by Sir Wm. Fairbairn will be found in his "Mills and Millwork."

3. If the wheel is to be built wholly of iron, and is to drive fast-running machinery such as a corn mill, the best method of building a large wheel is to replace the usual arms by simple tension rods, as in a bicycle wheel, the power being taken off by

a pinion gearing into a toothed ring secured to the inner edge of the shrouding. The more usual plan is, however, to take off the power from a spur wheel on the axis. In this case, however, the wheel is heavy, since much stronger arms must be provided, they having to sustain the bending moment due to the force transmitted to the centre. The axis and bearings have also to stand not only the weight of the wheel itself but also the water load, whilst in the case of driving from the rim it is obvious that the whole weight of water may be taken by the pinion, by correctly placing the pitch circle and gearing at the right height above, and distance from the centre. This method has not often been adopted (as far as the author is aware) in this country, the reason probably being that timber was cheap, the arms being always of this material, whilst iron was dear, especially when in the form of an accurate gear ring.

Overshot wheels may be divided into two classes, "forward" and "backshot." There is no essential difference between them in principle, but the latter is usual with large wheels fed from a multiple ported penstock, since the lowest port is considerably below the top of the wheel, and the length of the port chamber requires support. The former is usual with simple wheels in which the penstock discharges on to the wheel through a simple chute. The adoption of either type is determined purely by questions of convenience and cost, not principle. In some cases the wheel is made larger in diameter than the height of fall, and in this case the wheel is always a "backshot," and when very much larger, and the water is delivered on at 10 o'clock, it is said to be a "high-breast" and when at 8 o'clock a "low-breast" wheel.

The velocity of the circumference of an overshot wheel is more a question of convenience than of principle. If excessive, a certain amount of water is lost by centrifugal action, causing the buckets to spill too soon, and though with a well-designed

wheel the action is not seriously noticeable, the author has seen it occur on several occasions. Its effects are more prominent with old-fashioned wooden buckets, which cannot be made of such a good form as when of sheet iron, and are practically limited to one of two simple forms, known as "two-part" and "three-part" buckets. The highest speed the author has observed has been 12½ft. per second, but this was an extraordinary case, since the water was laid on to the wheel with a head of over 50 feet.

A more serious result of a high peripheral velocity is that the water has to be laid on to the wheel with a greater velocity, this causing a direct loss of head.

Leaving "breast" and "low-breast" wheels as requiring no particular treatment, we may pass on to consider the "undershot" wheels. This is the simplest possible type of wheel, consisting merely of a wheel with a number of flat-faced paddles or floats attached to the rim, the flat face being up stream. The Rennies made some careful tests of this type of wheel, which, whilst large and heavy, is only used on very low falls, and hence only a very low efficiency is to be expected. The results of Rennies' experiments were that the best effect was obtained when the speed of the centre of the floats was 55 % of the speed of the stream, and that at either above or below this limit, the work delivered from the axle was less. The efficiency was only about 35 %. The theoretical efficiency would be 50 % but for losses due to foaming of the water and friction of the axis. The type is of but little importance, and is only noticed here as an introduction to an American machine of almost precisely the same construction, but used under totally-different conditions, and known as the hurdy-gurdy wheel, and which is a specimen of American engineering.

In the early days of hydraulic mining in California, water, brought by channels from a great distance, was delivered at the mines under great pressure, very commonly as much as 500ft. of head.

Then, hydraulic appliances such as the "Girard" turbine were unknown, and the ordinary turbine, when possible to get it to the mine at all at a reasonable cost, ran at an excessive speed, the reason for which will be considered later on, and the wear and trouble given by footsteps, etc., under extreme heads was considerable. Added to this, the grit brought down by the water caused a rapid cutting of the vanes of the turbine, owing to the high speed at which the water passed through the narrow passages.

The mines being at a great distance from any engineering works, it was desirable to contrive some machine of a simple character, which could be built and repaired on the mine, and which could also be designed to run at any desired speed irrespective of the head.

This necessity resulted in the invention of the "hurdy-gurdy" wheel, which consists of a wheel of any required diameter, having on its periphery a number of nearly radial floats, and on which a jet of water impinges.

The best speed of the centre of the floats was found experimentally to be about half that of the out-flowing water, and under these circumstances the efficiency was found to be about 40 %.

It was also found that the speed of the wheel might be slightly varied from the *best* speed without seriously lowering the efficiency, the shape of the nozzle having a much more considerable effect. If the nozzle is not correctly shaped it is obvious that it will tend to set up eddies in the stream, and cause the jet to issue in a more or less broken stream, which will probably cause air to be entrained, and the "effect" of this broken water on the wheel will probably be less than that of a jet of *solid* water of equal weight striking the floats.

A wheel tested by Hamilton Smith, junr., at North Bloomfield, California, gave an efficiency of 43 % when doing maximum

work, and under those circumstances the speed of the wheel was 57 % of the speed of outflow of the jet. The nozzle in this case consisted of a tapered portion connected to a straight piece leading into the supply pipe. This wheel was 18ft. diameter and 17ft. 4in. inside the floats, and worked under a head of 312ft. The floats were 4in. deep, with flanges at each side, in which respect it differs from an ordinary undershot wheel. It is curious to note the general confirmation of Rennie's experiments, made under totally different conditions. This wheel has now been totally displaced by others of the "turbine" class, and giving practically double its efficiency, without at the same time introducing any considerable extra complexity.

Turbines have gradually replaced all other types of water motor, used under ordinary heads of say up to 800ft., their principal advantage being

(a) A smaller cost than a water wheel when used under great heads, and

(b) A greater efficiency, especially when used under small heads, replacing a "low-breast" or "undershot" wheel. They have also the advantage that they may be, in many cases, directly coupled to their work, thus dispensing with gearing, with its attendant loss and cost.

The general definition of a "turbine," as distinguished from other water wheels, may be said to be that the water is led into the wheel in a definite direction from guiding vanes or openings and, after traversing a defined path in the wheel, is discharged in such a direction relative to the earth as (when combined with the motion of the wheel) to more or less entirely destroy its motion relative to the earth.

A more easily understood difference may be said to be that, the energy of the water is obtained by the destruction of its pressure and momentum relative to the earth, instead of the utilisation of its weight by causing unequal loading of a wheel.

Before, however, considering the various types of true turbines, it may, however, be desirable that the author should briefly touch on two types of motor, known as "Barker's Mill" and "Whitelaw's Turbine." The former is shown in Plate 3, and, as will be seen, consists simply of two pipes radiating from the spindle through which the water is supplied. The water flows out of two holes in the arms tangentially to the circle described, and the arms and spindle are driven round by the reaction of the issuing water. The defect of this apparatus is that the centrifugal forces, acting on the water in the arms, increases the velocity of flow beyond that due to the natural head, and as the energy so supplied has to be supplied from the machine itself, it is evident that a loss of efficiency must result, since although the water flowing from orifices A will cause a greater rotative effort yet, as these are at right angles with the radial action, eddies are set up which destroy part of the head. The apparatus is in fact merely a toy, but may be seen in use as a revolving spray for watering lawns, etc.

A more ambitious machine is shown in Plate 4, the invention of Mr. Whitelaw, a Scottish engineer. His improvements consisted in making the arms of a spiral form, and of a gradually converging area, so that the water entering by the spindle gradually increases in velocity to the orifices A A, and being gradually diverted from a radial to a tangential direction, the radial pressure set up by centrifugal force exerted a reactive pressure against the sides of the arms, tending to cause rotation, and thus resulting in a smaller loss of power. The apparatus, as thus improved, gave, the author believes, an efficiency of about 60 % at its best speed, but as this speed in common with the "Barker's Mill" is equal to the velocity of outflow of the water from the orifices A A, the resistance that this apparatus is able to overcome is slight. There is, of course, in both "Barker's Mill" and the Whitelaw improvement, the loss due

to the backward velocity of the Water = $\sqrt{2gH + V^2} - V$ where V = the velocity of the wheel. Both suffered from instability of speed.

The next great improvement was made by Fourneyron, who was the first to introduce the true "turbine," having fixed guide vanes or ports. This was of the "outward flow," "reaction" type, the water flowing radially outwards from the centre to the circumference.

As it is necessary (for reasons to be afterwards explained) that both buckets and guides should flow full of water, the turbine was often made in two or more sections, the turbine being divided, by partitions normal to the axis, into practically two or more turbines. Thus, if divided into two parts, one part can be entirely shut off without affecting the efficiency of the other part. The principal disadvantages of this plan are that the loss by skin friction is slightly increased, and that the passages being small are more likely to be choked by weeds, leaves, etc.

The principal of fixed guide vanes is common to nearly all turbines. Jonval's turbine being the same in principle to Fourneyron's, being merely differently arranged. In this example the water flows through the guides and wheel parallel to the axis, discharging either under water or into a draft pipe, which, being air tight throughout, and dipping below the surface of the standing tail water, develops part of the head by suction. This type of turbine may discharge either upwards or downwards, and often in the case of a turbine with horizontal axis two are mounted on one spindle, and being enclosed in one casing are fed from between, the water flowing out at each end, and by this device the longitudinal pressure is neutralised.

Both these turbines are of simple type, discharging in one direction only, viz., either radially or axially, but the Americans, with their usual ingenuity, contrived a means whereby the dis-

charging area is much increased for a given diameter, thus lowering the cost and increasing the speed for a given power. This is done by causing the water to discharge not only into the centre of the wheel (radially) but also axially, by means of the spoon-shaped vane that may be seen at the bottom of any American type of wheel, and this type is therefore eminently adapted for confined situations, and where the quantity of water to be dealt with is large.

There remains a very excellent type of turbine of the "pressure" or "reaction" class known as the "Vortex," shown in Plate 5, and is the invention of Prof. James Thompson, a brother of Lord Kelvin. This turbine is an example of the inward flow type, the water passing inwards from the casing surrounding the wheel, and, being directed into the wheel by the movable guide blades, passes through the wheel radially to the centre, where it discharges upwards or downwards or both. The object of making the guide blades movable will be explained when considering the governing of turbines. The principle of "inward" as distinguished from "outward" flow is considered by the makers and the inventor to tend to steady running, since the centrifugal force increasing with an increase of speed tends to check the inflow of water from the guides.

Thus far the author has briefly described the principal types of turbine in use of the "reaction" class.

This class, however, suffers from several defects.

1st. Within narrow limits its radius is rigidly defined by the necessity of

(*a*) Keeping the guide and wheel passages constantly filled.

(*b*) The necessity for certain definite discharge openings of both wheel and guides.

2nd. A difficulty in "efficiently" governing them. It is quite possible for a wheel of this class to have an efficiency of 80 % at full load, and yet to fall off to 60 % at half load.

When required to deal with a reduced water supply this falling off is a serious matter, and a turbine builder should therefore be required to guarantee the efficiency of his wheel not only at full load but also at part gate, unless the water supply is at all times ample, when a cheaper wheel may answer the owner's purpose equally well, for unless storage can be made and used, it does not much matter whether the water passes through the wheel or over the waste weir.

As an example of the falling off in efficiency at part gate the author may give the following result of a test of a 240 HP Hercules turbine built by the Holyoke Machine Co., of Worcester, Mass., U.S.A., for the Neversink Mountain Electric Railway.

At full gate at 110 revolutions and 210 B. HP the efficiency was 80·7 %.

At half gate with the same speed efficiency = 74·4 %

Do. and at 100 revs. per minute = 75·3 %

this shows clearly the effect of the method of governing, in lowering the speed of best efficiency.

For most purposes, however, the speed is rigidly fixed between very narrow limits, and the ultimate efficiency must therefore be that at the required speed.

In this case, it will be noticed that with half the usual water supply the turbine requires 6·3 % more water per horse-power developed, and this example is not as bad as some which have come to the author's notice.

Referring to the point as to the radius being not subject to variation by the designer except within narrow limits, the author desires to point out that this sets a practical limit to the use of the "reaction" turbine under great heads. A certain definite quantity of water is required to develop a given power under the given "head." If this is large the quantity of water is small and the area of the discharged passages correspondingly

so. This fact, in conjunction with points of practical expediency, sets a limit to the discharging radius of the turbine, and this, necessarily resulting in a small wheel, makes the speed high, thus such a turbine runs at a high speed.

(*a*) Because the turbine is necessarily small in diameter.

(*b*) Because the velocity of outflow due to the head is high.

As an example, the author may mention one of Fourneyron's early turbines erected under a fall of 354ft., at St. Blaise, in the Black Forest. The turbine was of 30 E. HP, 13 inches diameter, and ran at 2,300 revolutions per minute. This speed was excessive when it had to be reduced by gearing, although eminently adapted for direct coupling to high-speed machinery.

The wear caused by trouble due to the high speed required under the high heads in the mining districts of California and elsewhere, led to the substitution for them of a nominally much less efficient type, viz., the "hurdy-gurdy" wheel.

The author may here point out that too much stress may be laid on "high efficiency," without regard to other points such as reliable running.

The object of mining, like every other business, is to "pay," and a mine can't pay if the mill is continually being shut down through the breakdown of the driving power. This the early Californian miners were evidently well aware of and preferred to pay more for water and to keep their mills running.

Further, it is quite possible in mountainous countries that the cost of carriage would amount to more than the capitalised value of the extra water used by the less efficient motor.

"Efficiency" counts for a lot but not for everything.

The introduction of the "Impulse" turbine disposed of most of the difficulties met with in dealing with very high heads. This type of turbine was originally introduced by Girard, a French engineer, and hence the type is often known as the "Girard Turbine." It differs from the "reaction" type in

that the wheel passages are never *filled* with water, and indeed special care is taken that they shall not be.

The water is discharged from the guides with the velocity due to the whole effective head, and passes over the curved wheel vanes in a thin stream, the energy being developed by the deflection of the stream by the curves of the wheel vanes, and is hence also known as the "Impulse" turbine. The circumferential velocity of the wheel is consequently lower than that of the "reaction" type, and there being no necessity to keep the wheel passages full, we are able to resort to "partial injection" when designing a slow-running wheel to work on a high fall.

In this system, the diameter of the wheel is chosen such that at the required number of revolutions the speed of the discharge face will be that determined by the velocity of the outflowing stream, whilst the area of guide ports is determined by the velocity of outflow from the guides, and this area may occupy one-fourth or even less of the circumference of the wheel, and we are consequently able to make the speed anything we please within wide limits.

Further, the fact that the wheel passages are never full enables us to regulate the water supply without loss of efficiency, for it is obvious that by shutting off one or more of the guide ports we can reduce the flow without affecting the hydraulic efficiency of the wheel.

The methods of regulating the water supply next claim attention, and it is in this respect that the "reaction" type is weak at part gate.

The most usual methods are as follows:—

REACTION TURBINES.

1.—Axial Turbines.

(*a*) A leather band is rolled up on a pair of rollers, so as to cover or uncover the ports in the guide chamber.

(*b*) Each port is fitted with a separate sluice, and they are lowered or raised in succession by a cylindrical cam.

(*c*) A throttle in the supply or suction pipe. This is the most defective method of any, and should only be used when a cheap turbine is required and when the water supply is ample at all times.

2.—Outward Radial Flow Turbines.

(*a*) A ring sluice is fitted between the wheel and guides, thus closing (more or less) the guide outlets.

(*b*) A ring sluice surrounds the wheel, and by rising or falling controls the outflow from the wheel as in (*a*). This latter is the method of governing adopted in connection with the Niagara turbines.

3.—Inward Radial Flow Turbines.

(*a*) There is only one of this type with the construction of which the author is acquainted, viz., the Vortex Turbine. See Plate 5.

It will be observed that the water is led on to the wheel by the curved guide vanes A, which are pivotted near their ends. The result of this is that a very slight movement of the guides causes a large variation in the size of the opening through which the water is discharged on to the wheel, and without much alteration in the angle at which it is so laid on.

Although the guides are shown as separate from each other, they may be and usually are connected together by links controlled by a worm and handwheel outside the case.

4.—Mixed Flow (American Type) Turbines.

Owing to the discharge taking place in two directions, viz., inwards and downwards, the only practicable method of regulating is a sluice fitting between the wheel and guides, in the clearance space.

One of the best of this type has a register gate turning as required to alter the opening of the guides. The gate has a number of ports cut in it corresponding to the guide openings, and the direction in which the water is laid on the wheel is not much affected by the partial closing of the gate. This device does not, however, get over the loss due to the disturbance of the relative areas of guide and wheel outlets, and the effect of which the author will now proceed to consider.

The speed of the discharging surface of a turbine is dependent, as before stated, on the velocity of the issuing water, and which velocity can be readily determined by the designer.

A well-known law of hydraulics lays down that the energy of a stream flowing in a closed channel may exist in two forms: (*a*) Kinetic; (*b*) Potential; and the law simply stated is that "the sum of the kinetic and potential energy is always constant," hence the velocity of flow in the different passages of a reaction turbine are always proportional to their area, and we have therefore a means of determining the velocity of outflow from the wheel, and hence of determining the speed of the turbine within certain rather wide limits by varying the ratio between the guide and wheel apertures. If the wheel orifices are small as compared with the guides, then the pressure in the clearance space will be large and the velocity of the wheel will be great.

The effect of this in conjunction with the different methods of governing is easily seen.

A sluice fitted between the wheel and guides as in Case II. and Case IV., and the movable guide blades in Case III. (*a*) will at part gate cause the velocity of outflow from the guides to be increased and the pressure in the clearance space to be decreased, therefore the speed of best efficicency as regards the wheel outflow is reduced, since this must always be equal to V × cos. A where V = velocity of outflow and A = angle of outflow.

When a ring sluice surrounds the turbine wheel as in Case II. (*b*) the effect of partly closing the sluice is reversed, since by so doing the area of discharge is reduced relative to the guides, and hence the speed of best efficiency is raised.

The effect of regulating by means of a throttle in the supply or in the suction pipe, is to reduce the total effective head acting on the wheel, and this is therefore equivalent to working the turbine on a totally unsuitable head. The effect is therefore that the velocity of the wheel is no longer equal to V $\times$ cos. A, and the water being thrown off with a forward velocity relative to the earth, due to the wheel running too fast, part of the energy of the water is absorbed in driving the turbine as a centrifugal pump, and the result is of course loss.

The alteration to the relative areas of discharge also originates another cause of loss.

The speed of rotation of the turbine is determined by the velocity of the outflow from the wheel vanes, the velocity of the inner radius of the wheel (if radial outward flow) not entering into the question.

The inner radius is determined by the angle of discharge from the guide ports and by the tangential component of the velocity of discharge. As a rule, however, the radial depth of the wheel is fixed by practice, and the designer then has to determine the "angle of entrance," since this angle must be a tangent to the entrance curves of the wheel vanes. See Fig. I., Plate 6.

Draw A B as a tangent to a radius of entrance of the wheel; draw C D so that its length = the velocity of flow from the guides, and so that angle D C B is equal to the angle of outflow from the guides. From D set off D E parallel to A B, making D E equal to the velocity of the entrance radius of the wheel vanes. Connect E C, then E C will be the direction in which the water enters the wheel, and therefore the entrance curves

must be struck from a centre on a line normal to C E, if the condition of entrance without shock is to be fulfilled.

It is further clear that if we partly close the wheel outlets, thereby reducing the velocity C D, then the relative direction of entrance will be along F C or the water will strike the back of the vanes, whilst if the regulation is effected by a gate in the clearance space, partial closing will cause the direction of entrance to be along H C, striking the face of the vanes.

From this it will further be seen that in an axial turbine (where the velocities of the inner and outer radii are necessarily different) the angles of entrance are also different, and the angles should in fact be calculated as if for a number of turbines of different radii.

It will be observed that this is the same method as that used to determine the correct angle at which to lay on the water to an overshot water wheel. Indeed, if it were not for practical difficulties the head lost in such a wheel in laying on the water might be recovered as "Impulse" by correct design.

Turning now to Fig. II., Plate 6, we have the same diagram as the last, but for a "Girard" or "Impulse" turbine, and it will be noticed that owing to the much greater velocity of outflow C D, as compared with the velocity of the wheel E D, the tangent E C is negative.

The method of regulation adopted is a slide moving over the entrance ends of the guide passages, and since the wheel vanes are never full the methods of regulation possible cannot affect the velocity C D to more than a very slight extent. The result is that this turbine gives a better efficiency at part gate than the "reaction" type, but it suffers from the necessity of keeping it clear of the highest tail water, which leads to the loss of from 6 to 12 inches of fall. Where the head is small or the tail water rises considerably in flood time this loss is serious, and the reaction type is probably the better one to use.

As remarked previously, the necessity for a simpler and more durable motor to work under extreme heads than the turbines procurable 40 years ago led to the introduction into California of the "hurdy-gurdy" water wheel. This wheel had a very low efficiency, mainly because it depended for its action entirely on the reaction caused by the collision of a jet of water impinging on the flat floats, and the exhaust water being thrown off at right angles to the plane of motion of the wheel no impulse was possible; in short, half the energy of the water was spent in shock, and in being discharged with only half its motion relative to the earth destroyed. Several inventors endeavoured to remedy this, and one of these inventions consisted in replacing the flat floats by semi-spheres or rather less. The jet impinging on the bottom of the cups split into two or more streams, passing away at each side and at the bottom nearly parallel with the plane of the wheel, but in a reverse direction to the motion of the cup, and with a velocity nearly equal to that of the cups, thus gaining the impulse which was previously lost. A defect in this wheel was, however, found to be that the jet in splitting, formed a wedge-shaped space filled with dead water, and this not being thrown off with the main body of the jet was "carried over," and after leaving the jet was thrown off radially, thus losing the energy contained in it. This defect was remedied in the Pelton wheel, in which the space so occupied is artificially filled with metal cast in one with the bucket.

The cups in this wheel are of a more or less rectangular plan, and having rounded bottom and corners. They are twin, the partition between the pair being brought to a sharp edge, so as to avoid any appreciable collision with the jet.

This wheel is largely used in mining districts, its principal advantages being:

1. Lightness.
2. Cheapness.

3. Ready adaptability to various heads.

4. Simplicity of construction and ease of repair.

Its principal disadvantage is a difficulty in efficiently governing it, the reason being that any reduction of the quantity of water must be effected by reducing the size of the nozzle tip, since a reduction of area at a larger part as by an ordinary sluice valve will obviously affect the velocity of efflux of the jet.

The best velocity of the jet being theoretically (and practically) equal to twice the mean velocity of the buckets, any reduction of the velocity of the jet will obviously prejudicially affect the efficiency by causing the impulse streams to have a motion relative to earth (in the positive sense, if wheel is running too fast) proportionate to the reduction in velocity of the jet.

This difficulty is surmounted in several ways.

1. For a more or less permanent alteration of power a smaller or larger jet may be substituted for the one in use.

2. A number of nozzles may be set to play on one wheel, each nozzle being controlled by an ordinary throttle valve. One or more nozzles being then entirely closed will not affect the efficiency of the rest, whilst the partial closing of one nozzle will only affect the efficiency as regards *that one jet.*

3. A special nozzle is supplied by the Pelton Water Wheel Co., of San Francisco, California, provided with two shutters sliding across the face and made to approach or recede from each other by a right and left hand screw, operated either by hand or by a governor.

4. A Pelton wheel was built by Mr. C. L. Hett, provided with a nozzle having a taper stem fitting into it in a similar manner to the steam and water cones of an injector, and which could be made to pass more or less water through the nozzle by drawing it back more or less by means of a screw and handwheel.

It is necessary with this class of nozzle that the stem or regulating cone should be of such a shape as to give a uniform reduction of water area from back to front. It is obviously of no use to throttle the water at the back and then allow it more than proportionate area at the tip, since this will cause a reduction of the velocity of outflow, or at best broken water, which is just what we are trying to avoid. This would seem to imply that the point of stem should be flush with the nozzle when full open, and should be brought to as sharp a point as practicable, so as to leave as small a space as possible in the centre of the jet, to entrain air, and that the water areas round the stem and enclosed by the nozzle should be (proportionally to the velocities at each point) at least as large as the smallest area of the jet, and preferably rather larger.

An efficiency of upwards of 85 % is claimed for this motor under heads of 200ft. and upwards, and although the author is not in a position absolutely to either confirm or reject this claim, such information as he has been able to get seems to imply that a very high efficiency has been obtained.

The author has not yet been enabled to obtain an independent and accurate reliable test of this motor, but there is no theoretical reason why it should not give very good results.

The cost of providing it with a really efficient control of its water supply would, however, probably tend to reduce its principal advantages in the direction of cheapness and simplicity as compared with the Modern Impulse Turbine.

To conclude this part of the paper the author may say that he has often been asked, "Which is the best turbine?" The reply will be obvious, that there is *no* "best" turbine; but every case must be considered on its merits, and with reference to all the circumstances of the case.

STORAGE, CONVEYANCE AND MEASUREMENT OF WATER.

It is seldom that any great head can be obtained without more or less expensive works of conduits and storage, and it is therefore desirable to consider some of the methods already used for this purpose.

The water supply to the hydraulic mines of California and elsewhere, is often brought from great distances, 20 miles being common and 50 not out of the way.

The original dams which formed the reservoirs in the mountains, were of a character that would shock an English engineer accustomed to large earthworks or expensive masonry constructions; but it must be remembered that in many cases the cement or lime for masonry would have to be brought hundreds of miles from a railway or seaport, and the stone was often not of a character that could be economically quarried in large blocks, and at the same time, labour was expensive. The result was that the dams were often formed of a timber crib work bolted to the rock, and the various timbers bolted to each other. The whole was loaded with rip-rap quarried on the site and rendered water-tight by a sheeting of planks (caulked) on the water face.

With the decay of hydraulic mining in California and elsewhere, and the discovery of more permanent uses for the water provided, many fine examples of masonry dams have been erected in the United States. Their general construction has, however, been well treated elsewhere, whilst the details of their construction affords scope for a separate lengthy paper. It may, however, be well to point out that the best possible construction above ground is of no use if the greatest care is not exercised in obtaining a satisfactory foundation.

The failure of Bouzy dam in the Spring of 1895 was due to sufficient care not having been taken in this respect. This dam was founded on an excellent foundation of clay,

but this not covering the whole site of the reservoir, allowed the water to get at a non-water-tight bed underneath, with the ultimate result that the whole dam slid bodily on its foundations, and, although its height was small (only 50ft.), its failure caused large loss of property and life. The height of this dam was 75½ft. above its foundations. The failure of the Conemaugh dam, Pennsylvania, which burst some years ago, was due to another cause. It was built of loose stone, with the interstices filled with smaller stones, and its failure was due to a heavy flood topping the dam and washing away the smaller stones, when its collapse was only a question of time.

Such dams should be treated with just as much care as if of earth, and ample waste weir accommodation should be provided. They should also be well drained from the bottom, since water finding its way inside may accumulate and cause such a pressure as to burst out the lower face stones and form a risk of accident. Similar dams are not, however, likely to be built by qualified engineers in populated districts in the present day.

The above remarks had scarcely been written when the "Engineer" reported the failure of two old dams in the U.S.A.

1. Goodrich reservoir, 15 miles from Baker City, Oregon, on June 16th. This was built for mining purposes in 1863.
2. An Irrigation dam burst at Brigham City, Utah, June 7th. This is said to have been built by settlers, without the advice of engineers.

The Author has no special knowledge of the construction of these dams, but it is obvious that the safe life of a crib-work dam is limited by the decay of the timbers, and when these are buried in stones the cost of repairs amounts to practically that of a new dam, and repairs are therefore likely to be put off too long.

The methods of conveying the water from the reservoir to the power house are various.

For any considerable distance we are, however, limited in practice to open channels, and where the ground is too steep for these, to timber or iron flumes, since both the loss of head and the cost prohibit the use of pipes for long distances.

There are many formulæ for calculating the flow of water in channels, but the reliable ones are complex, and except for important works, a simpler formula may be used such as that given by Bowie in his treatise on Hydraulic Mining, viz.:— velocity per second $= c\ (R\ S)^{\frac{1}{2}}\ (= c\ \sqrt{R\ S})$, where

C = a constant determined by experiment.

R = the hydraulic mean depth.

S = sine of the slope.

If C had to be determined for each case it would be useless, but when used with judgment and the probable value of the constant determined from previous experience it is a useful working formula.

The value of C, as deduced from measured results on actual ditches in California and elsewhere, for rough sides in rock and earth is about 40, and for unplaned timber, as used for flumes, about 55. These results are lower than the best and higher than the worst examples; a liberal discount must be taken off when applied to ditches with a very winding course or abrupt turns. The constant also takes account of leaks, &c., on the route as the ultimate discharge was taken from a length of from 10 to 20 miles in the case of ditches.

The constant also applies only to grades of about 16ft. per mile in the case of ditches, and of 32ft. per mile in the case of timber flumes.

With large channels and flat slopes "C" is much larger.

An example is given in the accompanying table, the data being taken from a paper on the flow of water in the new Loch Katrine aqueduct, by Mr. A. F. Bruce, M.I.C.E., (Proc. Inst. C.E., vol. cxxiii.)

It will be observed that the value of "C" in the formula $v = c\sqrt{RS}$ is but slightly different from that given by the elaborate formula of Kutter.

In the formula "C" $= \frac{v}{\sqrt{RS}}$ where v = the observed mean velocity of the stream.

This formula is merely a simplified form of Kutter's, and is not so accurate, though near enough for ordinary practical purposes.

Depth of Water in Aqueduct.	Cross Sectional Area. Sq. feet.	Discharge over Gauge Weir.	Mean Velocity in feet per second.	Hydraulic Mean Radius.	Co-eff. of Discharge. (Kutter.)	"C" in formula $V=C\sqrt{RS}$
Ft. In.						
1 $8\frac{5}{8}$	14·225	26·620	1·8714	1·2273	125·35	129·2
2 $2\frac{3}{8}$	18·692	41·423	2·2161	1·4896	134·59	135·1
2 $2\frac{3}{4}$	19·765	42·89	2·175	1·5469	129·62	130·2
2 5	20·774	45·832	2·2062	1·5990	129·33	129·7
2 $8\frac{3}{4}$	23·687	53·504	2·2588	1·7403	126·92	126·1

Of course when the works are on a large scale, and warrant the application of greater time and thought to their design and construction, a more elaborate formula may be used, such as that of Kutter. It is, however, of no use making elaborate calculations when the works are as roughly executed as is common in mining work.

The flow in a channel depends (for a given grade) on the hydraulic mean depth, which is expressed as:—

$$\frac{\text{area of water section.}}{\text{length of wetted surface of channel.}}$$

It is desirable to keep this quantity as large as possible, both because it enables us to reduce the gradient, or, on the other hand, to reduce the cost of excavation. Practical considerations,

however, largely affect the section ultimately adopted, and no general rule can be stated. The velocity must not be so great as to cause scour in soft beds, or, on the other hand, so slow as to cause rapid deposit.

The limiting angle of repose of the banks and the necessity of a margin against scour will ultimately determine the slope of the banks, but it is obvious that a circular cross section is the most economical in excavation. This section will not, however, stand in soft material unless lined, which increases the cost. It is useful therefore to know that a similar mean depth to the semi-circular is given, by making the bottom width equal to the depth and sloping the sides as tangents to a semi-circle of a radius equal to the depth of water. The hydraulic mean depth will then be equal to half the depth of water in each case. The section is shown in Plate 7.

It must be borne in mind that the loss of head is proportional to the grade of the channel, whilst the reduction of area and cost of excavation only varies inversely as the square root of the grade, so that a limit is set to the economical grade in every case.

Further, with a steep grade the water cannot be brought to a stand when not used, as it will top the bank at the lower end.

These two causes together, operate to prevent any more than a sluggish current in large conduits supplying water at a low head, the flow head being obtained largely by the inclination of the water surface instead of by the bed of the channel. Such channel should supply the water with a velocity not exceeding about 1ft. per second, and should be as much less as practicable. If the "flow head" is great the water may be lowered to such a point as to set up a vortex over the turbine or supply pipes, causing a tendency to entrain air and leading to loss of effect in addition to the direct loss of head.

When using pipes to supply water to turbines it is important that they should be large enough to supply the required quantity of water without undue loss of head by friction. The turbine should be designed for the total head less the friction loss, otherwise good results cannot be looked for.

There are many formulæ for calculating the flow of water in pipes, but none of them can be fully relied on, and a large margin should always be added to the calculated diameter. It should be remarked that the discharging power of pipes varies much more rapidly than their areas, so that a small addition to the diameter will largely reduce the frictional loss.

From a comparison of a number of experiments the author has concluded that Neville's formula is sufficiently accurate for most purposes when the pipe is not of extreme length and small diameter.

The calculated diameter should be increased by from 10 — 15 % to be on the safe side.

This applies to rivetted pipes.

The formula may be expressed:

$$v = 140\sqrt{RS} - 11\sqrt[3]{RS} \quad \text{where}$$

v = velocity of flow, R = hydraulic radius, and

s = sine of the slope.

Thus, if with a certain head and gradient a 12in. pipe discharges 446 gallons per minute, a 24in. pipe will discharge 2,652 gallons, or nearly six times as much instead of four times.

The subject of the construction of steel pipes has recently been dealt with by Mr. Stewart, of Glasgow, so that the author does not propose to deal with the subject very exhaustively. He may remark, however, that there is an advantage in using rivetted pipes over those welded, when freight is heavy, in that they can be more easily bundled for shipment when merely

rolled to the required curvature or left flat and bent on the job. The tonnage on which freight is paid is then less. Against this saving there must be set the cost of the rolls and rivetting; but there is a further saving in that the sheets may be thinner than when welded, as a certain thickness is necessary for that operation. American practice allows a strain of 13,000lbs. per square inch of gross plate section, and as far as the author has ascertained these pipes give no trouble, even when exposed to hard frost and hot sun. A table is here given showing the stresses on the plates of a main supplying the city of New Westminster, B.C., the data being obtained from a paper read by Mr. A. E. B. Hill before the Institute of Civil Engineers.

Diameter of pipe 14 inches.

Thickness of plate.	Test head.	Stress on full-plate section.
0·148 inches.	675 feet.	13,800 lbs.
0·134 ,,	625 ,,	14,100 ,,
0·120 ,,	525 ,,	13,300 ,,
0·109 ,,	425 ,,	11,850 ,,

This is calculated on the test pressure, and the engineer stated that tight joints were always obtained. The plates were cut to size in Glasgow, but bent and double rivetted on the job.

The working pressure was not stated, but as regards the lower working pressure than that stated previously it must be remembered that this was a permanent job for the water supply of a large and growing town. It was stated that no difficulty was experienced from frost even where exposed; indeed, the author has never heard of any serious difficulty from that cause where water under pressure in such pipes was kept moving.

The following table is given extracted from a paper read by Mr. Hamilton Smith, before the Iron and Steel Institute, 1886, and will show the pressures common in mining practice.

NAME.	Diam. in inches.	Head of Water in feet.	Maximum tensile strain in lbs. per square inch.	Description of Pipe.
Cherokee.....	30	887	17,549	Plate iron, double rivetted.
Virginia City.	11	1720	about	Plate iron, double rivetted.
	10	1720	15,000	Lap welded tubing. Screw couplings.
Texas Creek ...	17	760	ab 18,000	Plate iron, double rivetted.
Humbug Canon	26	120	11,500	Single rivetted iron 1⅛in. thick.

Another example is that of a section of pipe used at North Star mine, California, under a head of 775ft.

Thickness = 0·22in. diameter = 20in.,

and tensile stress = 15,300lbs. per square inch gross plate section.

The pipe was, in this case, hot double rivetted.

The author has been much struck by the large use of wrought iron and steel pipes in foreign countries as compared with this country. Questions of cost of carriage no doubt largely operate to decide the question of wrought iron *versus* cast iron.

A ready means of stopping slight leaks in these extremely thin pipes is to close the lower end and to empty a bag of bran or sawdust into the upper end. The current of water flowing through the leak carries the sawdust into the leak and eventually stops it.

Of course, for more permanent and important works, it is better not to strain the pipes so heavily, and the extra thickness will enable perfectly tight joints to be obtained throughout.

As showing the necessity for considering the loss of pressure in pipes for power purposes, the author may instance the city of Wellington, N.Z. This city was electric lighted by vortex tubines, (built by Messrs. Gilkes and Co., of Kendal), of 50HP, working under a nominal head of 276ft., and the city authorities complaining of the light given, the company interested, stated that they

were not responsible, inasmuch as the pressure of the water supplied by the city fell off at times, and that in consequence the speed of the dynamos was reduced.

When laying a pipe line care should be taken to avoid, as far as possible, any rise above the "hydraulic gradient." Assuming that the pipe is of uniform bore for its whole length, this gradient will be a straight line connecting the elevations at each end of the pipes corresponding to the pressures. When no flow exists in the pipe this line will take up a different position relative to the pipe than when flow is permitted. It is the latter that has to be considered. In fact, it will be obvious that, when no flow exists, the line of gradient is horizontal, and its downstream end will be vertically depressed when flow is permitted by the head lost in the conduit (measured in feet usually).

Thus in the case of an inverted syphon, discharging full bore, the line of hydraulic gradient will be a straight line touching the ends of the pipe.

Wherever the pipe line rises above the gradient, air will accumulate, and may do so to such an extent as to stop the flow of water. Even where the line does not actually rise above the "gradient" line but only approaches it, air will accumulate, and may interfere with the flow. At these points, air valves should be placed to discharge the air before it has a chance of being troublesome.

Of course, if the pipe line rises *above* the gradient a vacuum will tend to exist, and therefore automatic air valves are inapplicable, and any accumulated air will have to be pumped out.

A rise of 30ft. or so (depending on the pressure of the atmosphere) above the hydraulic gradient will necessarily stop the flow when full bore, since the pipe is then in the position of a syphon in which the height of the short limb is longer than the corresponding atmospheric column.

As regards the measurement of water the most common method is by weir. In this method, the water is dammed back by a thin-edged board until brought to rest above the weir. If the water has any sensible velocity of approach this must be measured, and the head due to approach added to that measured on the weir. The "head of approach" $= \frac{v^2}{2g}$ theoretically, where "v" = velocity of approach, and "g" = the value of gravity.

The value of "v" should be measured as accurately as possible by means of a float of a depth equal to the height of water on the weir.

It should be remarked that this height should not be measured actually on the weir itself, but some distance back from it, since the stream of water contracts when near the overfall. The measurement may be conveniently taken from the top of a peg driven down until level with the edge of the weir. It should be taken with great care, since the height to be measured is small, and a slight error will largely affect the result. For accurate work a hook-gauge is used, the reading being taken when the point of the hook is flush with the water surface. It reads against a fixed scale, and is adjusted to read 0 when the point of the hook is level with the edge of the weir. Its *raison d'etre* is that capillary attraction will cause the water to rise round a scale immersed in water, thus leading to incorrect reading. If the hook-gauge is used in a steam having any appreciable motion it should be enclosed in a box and fed by small holes bored in the sides, facing across the stream. A number of readings should be taken, and the mean taken as the true one for the pupose of calculation, so as to reduce the error of observation as much as possible.

Care must also be taken to have a clear overfall; in other words, the weir must not be drowned. Except in the case of

very small quantities, the edge of the weir should not be less than 12in. above the tail water level.

The lip of the weir should be kept as long as possible relative to the width of the stream, as if very short, the stream will contract in a horizontal plane for the same reason that it contracts vertically.

The author gives here a few formulæ for the calculation of discharge from weirs, but he cannot vouch for their strict accuracy. The authority is given in each case:

Molesworth, 23rd edition.

$C = 5{\cdot}15\ H^{\frac{3}{2}}$

C = cubic feet per minute: H = depth of water in inches.

Effective length of sill = length $- 0{\cdot}2 \left(\frac{H}{12}\right)$ Length of sill measured in feet.

This formula is based on experiments by Mr. Blackwell, on the Kennet and Avon Canal in 1851, and embodied in a paper read before the Institute of Civil Engineers on May 6th of that year.

The coefficient here given (5·15) appears to only apply to a notch nearly the full width of the stream, the sill being formed of a thin plate, and when the head is from 3in. to 6in; when "H" is from 1 – 3 inches C = 5·76, and from 6 – 9 inches C = 4·52. It is therefore clear that this formula, like others, must be used with discretion.

Francis's formula, used in gauging water at Holyoke testing flume, is as follows:—

$Q = 0{\cdot}416\ L \times (2\ gh)^{\frac{3}{2}}$ where Q = cubic feet per second. h = depth of water in feet and L = length of weir in feet, where there are no end contractions, or, in other words, where the weir edge is the full width of the stream.

Where the weir is not the full width of the stream, so that contraction occurs in the stream in falling over.

$Q = 3{\cdot}33\ (L - 0{\cdot}1\ n\ h)\ h^{\frac{3}{2}}$ n of course in most cases = 2.

This formula is largely used in America, and appears to compare fairly well with experimental results.

Where the water to be measured is very small in quantity it is convenient to measure it through a right-angled triangular notch, and Thomson's formula for the discharge is G = 1·91 × H 2·5 where H. = depth of water above bottom of notch in inches, and G = gallons per minute.

Every form of overfall has a coefficient of discharge of its own, and the only safe plan is for the engineer to make his measuring weir correspond as closely as possible to one for which the coefficient has been experimentally determined.

The author inserts these formulæ into the paper for the sake of completeness, but he does not wish to be thought to personally guarantee their correctness. Measurements of weir overflow are surrounded with difficulties, and very great care is necessary to obtain accurate results.

Another method of measurement is by floats. If the stream to be measured has a fairly uniform cross section, and tolerably free from eddies, this is a simple and fairly accurate method.

A considerable length should be chosen as straight and regular as possible. The floats should be long enough to nearly touch bottom, but not so long as to catch on shallow parts, and should be loaded to swim upright. They should also not appear much above the surface, so that wind shall not affect them. Experiment has shown that the velocity of such a float is very nearly equal to the *mean* velocity of the stream, the velocity of which is of course not uniform throughout its depth, owing to the influence of the bottom and sides of the channel. A number of floats should be started and timed as accurately as possible, and the *average* velocity so found multiplied by the average cross section of the stream gives the discharge. This method is

usually the only one applicable to mountain streams, since it is practically impossible to dam them back at any part to stillness.

In mining practice, water is often measured by the "inch," the water being led from the ditch into a wooden box. In one side of this box is a slot closed by a wooden slide, which can be drawn out so as to allow the water to spout through an opening of greater or lesser area as required, the "miners' inch" being the quantity of water discharged per square inch of area of opening under the given head.

The "inch" is commonly measured on a two-inch (vertically measured) opening, with a head of 7in. above the centre of the slot, this corresponding to an actual discharge of rather more than 1·5 cubic feet per minute.

Other "inches" are measured through a 1in. opening, with heads varying from five to nine inches. It is therefore necessary to specify what inch is meant when writing from abroad.

Its origin was the necessity for a simple means of measuring the water supplied to the different customers of a water company, and for this purpose, the time during which the water was assumed to flow was stated. This time varied.

One "inch" was equal to 1·76 cubic feet per minute for 11 hours, and was therefore equal to 1,161·6 cubic feet. Another was 1·54 cubic feet per minute for 24 hours = 2,217 cubic feet.

Mr. Roberts, in the paper referred to further on, stated that the Water Company supplying the "North Star" mine consider the "inch" as equal to 1·45 cubic feet per minute, and charge 7d. per day for each inch, a rate of practically 3¼d. per 1,000 cubic feet.

In the earlier part of this paper allusion was made to the question of storage of water for power purposes, but the method was not mentioned, which is in successful operation both in Zurich and in Geneva, and to which it is desired to call your attention.

This method, which he has advocated for several years past for electrical purposes, consists of pumping water through a line of pipes to a reservoir at a considerable elevation. It may, at first sight, appear impossible that anything but loss could possibly result from such a system. When carefully gone into, however, it will be seen that owing to the large variations in the load on an electric lighting station, if a water power is capable of dealing with anything more than light loads, the greater part of this power is wasted, since the average out-put is usually only from one-eighth to one-tenth of that possible were full load maintained during the entire 24 hours, and the result is that steam, or other power, has usually to be maintained to get over the peak of the load diagram, and, as water powers are not often situated in the most convenient places, the cartage and incidental costs on the fuel are heavy. The system proposed, therefore, would enable a water power, too small whilst unaided to be of any use for public electric power supply, to undertake the lighting of a town of some considerable size.

The author's calculations lead him to believe that the total loss over the whole of the machinery would not exceed, on an average, 50%, and consequently, if a supply is given on a load factor of $\frac{1}{10}$, an original water power of 50 HP would be capable of dealing with a maximum load of 5,000 lights of 8 candles. Very small, compared with the Manchester Central Station, but big enough to efficiently light many small towns.

If the town grew beyond the capacity of the water power a small steam, or other pump, working constantly at full load, and therefore at its best as regards both fuel and capital costs, would deal with the increase of load, and, as regards the items of fuel, it is well-known that the large fuel consumption of electric lighting stations is due to the necessity for maintaining full speed at extreme light loads. The probable saving of fuel by maintaining an absolutely steady load is so great that the author

believes it to be possibly worth while pumping the water by steam and storing in the way proposed, when the value of the fuel saved would pay interest on a considerable outlay of capital. There would also be a considerable saving in the prime cost of engines and boiler, in place of which is substituted a pipe line and fittings, costing rather more, but having a longer life without extensive repairs, and a reservoir which (bar earthquakes) costs next to nothing for repairs and cleaning out.

In addition to the saving on coal account, there is also a saving in the cost of labour.

Of course, where a dam can be built, storage by that means would be cheapest, but this is seldom the case owing to interference with the rights of others and the cost of necessary land. To deal with such a system as the one proposed for 5,000 lights, merely requires a pipe track 10ft. wide at most, and a reservoir 100ft. square by 10—12ft., assuming the possible head of 300ft. The subject is too large to be gone into at the end of a long paper, and he will therefore say little more than to recommend it to your careful attention, and to say that there are many places in this country where such a system could be applied with advantage, especially in the mountainous districts.

The author has seen more than one place where a line of pipes, scarcely half a mile in length, would enable a head of, at least, 300ft. to be obtained, and, at a reasonable expenditure of capital, would obviate the necessity of any expenditure on fuel for power for years to come.

There are two obstacles in the way, however.

1st. The average man looks at the capital outlay, and not at the ultimate saving that a judicious outlay will bring him.

2nd. The inhabitants of small towns seem to be indifferent, and are afraid to "venture."

3rd. The trouble of obtaining a provisional order is considerable, and the cost is heavy on a small undertaking.

4th. Bad work. The author is aware of a small town in North Wales which was electrically lit by means of a water power. The people were so dissatisfied with the light that custom fell off, and the concern collapsed. *There* was a good chance wasted, since there was practically no competition. The author has good reason for believing that this failure did considerable damage to electric lighting in general, and to such use of water power in particular, in that district.

The author has often heard, and read, with some amusement, people's remarks about (water) power for nothing. They apparently forget that the much-maligned capitalist requires a return for his money, and the works require repairs and renewal; these facts rather spoil the effect of the "free gift of nature."

Further, some persons ideas are vague, to say the least of it. It is not long since the author read of a paper by a well-known Engineer, in which, speaking of the water power wasted in this country, he drew special attention to the Vyrnwy water works, apparently forgetting that the "power" is not there wasted, but is used up in driving the water against the frictional resistance of the conduit.

A few details concerning one or two more or less large works are appended.

The Laxey water wheel has above already been described, and the photograph handed round will give a good idea of its construction, though many of you have no doubt seen it.

At Geneva, the Rhone is made use of to the extent of 6,000HP, which is used partly for pumping water for domestic supply, and partly for supplying power through wire ropes and high pressure water to various factories. It is also used to drive the electric lighting station, the water for this purpose being stored in a reservoir during times of light load, and giving a head of 390ft., exclusive of frictional loss in the pipes. As it was necessary

that the water pressure should be maintained as nearly constant as possible, the loss of head by friction in the 16in. main is compensated for by passing the water through a centrifugal pump when the water is flowing from the reservoir.

The speed of the turbine driving this pump being automatically controlled by the pressure in the main on the town side of the pump, a nearly constant pressure is maintained. The reservoir, in this case, stores 453,000 cubic feet of water, which, at the head named, equals 5,573 horse-power-hours (gross), and costs about 25/- per horse-power-hour stored.

A similar system is in use at Zurich, where the head is about 475. The "efficiency" of the whole system as far as the author has been able to ascertain is 60%, and full information concerning the Zurich works will be found in a paper by Preller, read before the Institute of Civil Engineers in the session of 1892-93.

A good example of high-pressure work is seen in connection with Pelton water wheel at the North Star gold mine, California, a description of which is extracted from a paper by Mr. Roberts, read before the Institution of Mining and Metallurgy in 1896.

The total head is 775ft., the effective head being rather more than 716ft.; the principal loss occurring in the old pipe line to which the new line is connected.

The length of the old line is 13,200ft., and diameter 22in., and giving a head of 440ft.

It is interesting to compare the results of calculation by Neville's and D'Arcy's formulæ.

The loss of lead on this pipe = about 51·48ft., and the velocity was 4·1ft. per second.

The "hydraulic radius" R = 0·458, and the sine of slope = 0·0029.

Assuming that the pipe was discharging at full bore under the given lost head = 51·48ft.

By Neville: $v = 8{\cdot}428$, or about 12% too low.

,, D'Arcy: $v = 8{\cdot}621$, or about 11% too low.

The length of the new line is 7,077ft., of 20in. pipe.

The water is delivered on to a Pelton wheel 18·66ft. diameter, over all and keyed directly to the crank shaft of the air compressor, which it drives.

The theoretical velocity of the out-flowing jet under the stated head is 215·4ft. per second, and the wheel is accordingly set to run at 110 revolutions per minute, which gives a peripheral velocity about equal to half that of the depth, with buckets 8in. in radial depth. The theoretical discharge of the jet, which was rectangular 2in. × 1⅜in., or 2·75 square inches, would be 246·5 cubic feet per minute, under a head of 716ft., corresponding to 335HP.

The horse-power (as shown by the indicator card) on the compressor was stated to be 258, and the lowest possible efficiency would evidently be more than 258 ÷ 335 = 77% over all reckoning from jet to air delivered.

Allowing efficiency of compressor to be 90%, and allowing 8% for contraction of the jet, then the hydraulic efficiency of the wheel would be nearly 89%, giving an efficiency which the author thinks would be hard to beat and supporting Mr. Roberts' measurement, bringing out the efficiency of the wheel at 88·1%.

The actual quantity of measured water was stated to be 240 cubic feet per minute.

The wheel is seen in the blue print kindly lent the author by Messrs. Fraser and Chalmers.

Another illustration of the use of high-pressure water is found at the Comstock mines, Virginia City.

The water is taken from the pipes of the Gold Hill Water Company, at a head of 460ft., and taken down a shaft to a depth of 1,640ft., giving a total of 2,100ft. The wheel has a solid steel plate centre and phosphor bronze buckets. The pressure

given by such a head is 911lbs. per square inch, or more than 80% in excess of the pressure supplied by the London Hydraulic Power Company.

A properly formed nozzle, ½in. diameter, will, under this head, pass enough water for one hundred effective horse-power, reckoning the co-efficient of contraction at 0·95.

Allowing a velocity of 8ft. per second as the flow of water in the pipes, their diameter would be only some 7in., and a loss of head in 3,000ft about = 21ft., or only 1%.

Of course such a head as this can only be obtained under exceptional circumstances, and in this case the tail water was carried away through a tunnel which was driven by a Drainage Company, for the purpose of draining the upper levels of the mines on the Comstock lode.

The diameter of the wheels is 36in., and runs at a speed of 1,150 revolutions per minute. This installation was an extension of an older one carried out by the Brush Electric Company, consisting of six 44in. Pelton wheels, coupled to as many Brush dynamos, the water supply being the tail water from an existing 10ft. wheel, and taken down the shaft by two pipes of 10 and 8in. diameter. The efficiency of these wheels was stated to be 88%, but the author has no means of checking this statement. It is, however, probable that the wheels under these extreme heads would not be of such a high efficiency as at lower (although probably better than an impulse turbine), owing to the extreme velocity of the water through the nozzles, and their small diameter.

As showing the terrific force of a jet of water under these high falls the author may quote the experience of the owners of Fresno (Cal.) Electric Plant, operating under the head of 1,411ft.

The diameter of the jets playing on the Pelton wheels at an angle of 45° is 1⅛in., and when allowed to strike the bottom of

the concrete wheel pit it quickly bored through and through the bed rock underneath and appeared in the station building.

The bottom was then sheathed with 3in. planking, and for 3ft. round the nozzle with $\frac{3}{8}$in. steel plate.

A $\frac{1}{4}$in. jet having been accidentally left in, in three days it had, in conjunction with the granitic grit in the water, worn through both plate and planks, and had started on the concrete bottom.

The author has observed that the principal difficulty in governing these wheels occurs when small powers are wanted with high pressure of water, and would suggest that in such cases it might be desirable to reduce the pressure by means of such an instrument as Greathead's Injector Hydrant; the wheel would then be mounted on a water tank, the water being caused to circulate through the wheel (the spent water falling back into the tank) by means of the "Injector," and the overflow, being measured, would be the quantity of high-pressure water used.

A plant was used for some years by Mr. F. Higgins (of the Exchange Telegraph Co., London) for charging accumulators in connection with his telegraph system, the water used being obtained from the mains of the London Hydraulic Power Co.

The plant consisted of a three-cylinder Brotherhood engine, belted to an old-fashioned "A" gramme dynamo, and was run for six and a half hours, the quantity of water used during that time being 7,700 gallons.

This corresponds to 59·2 horse-power-hours neglecting small fractions, and as the sum of electrical work done and internal losses = 30·4 the effect of the hydraulic motor, belting, &c., = $\frac{30 \cdot 4}{59 \cdot 2} = 51 \cdot 3\%$.

A Pelton wheel has now been substituted, and Mr. Higgins says that it gives precisely the same output for 10% less water. The pressure = 650lbs.

The author cannot give any reason for the low efficiency in this case, but suggests that it may be accounted for by the very small size of the nozzle necessary, thus causing abnormal frictional loss at the jet, or that the water supply was throttled in some way.

The mechanical losses have not been measured directly, so that the efficiency of the three-cylinder engine would be about 56%, allowing 5% for loss in belts, &c.

Allowing a co-efficient of contraction = 0·8, a jet having a diameter of 0·094in. will pass sufficient water for two hydraulic horse-power under 1,500ft. head, which fact will give some idea of the large frictional losses likely to occur with small powers under this head.

To conclude, it is hoped that these somewhat scattered remarks will be of interest and of some profit to the members of the Association, although it is difficult to deal effectively in a single paper with such a large subject as "Water Power." There appear to be a number of small towns in the north of England and Wales where water power might be effectively used for electric lighting purposes, in which application the author is principally interested.

The inhabitants of these small towns do not, however, appear to be inclined to, or have not the money to, embark on what, to them, is a new business, and to work this field outside capital is needed.

During a tour in North Wales, in the dry summer of 1895, the author came to the conclusion that ample water power existed to light many small towns. Whether such power could be rendered available at a lower cost than from coal is a question only to be solved after careful consideration of each individual case and after measurements have been made, both of the quantity of water available, and the head under which it can be applied.

The author, to conclude, desires to acknowledge the assistance and details given to him by Mr. Reddicliffe, of the Great Laxey Lead Mining Co., and also by Messrs. G. Gilkes & Co., and Messrs. Fraser & Chalmers, and others.

DISCUSSION.

The PRESIDENT (Mr. J. Nasmith) said the question of water power had in this country been unmistakably neglected, and he presumed this would continue to be the case so long as they could buy coal at from 6s. 6d. to 7s. per ton, delivered at the boiler-house door. The day, however, was coming when they would not be able to buy coal at that price, and when, indeed, there might be some difficulty in finding coal at all, other than that "made in Germany." Anyone who had followed what had been happening in Durham during the last few months was aware that, one by one, large collieries, which hitherto had turned out enormous quantities of coal weekly, were being gradually closed, owing to the fact that it did not now pay to win the coal. Coal pits were getting deeper and lower in order to reach seams that could be worked, and, although one laughed at the allegation that the coal-supplies of this country were going to be exhausted, he believed that there were tangible evidences of the fact that unless new and large coal-fields were found, it would not be a very great number of years before they would find their coal-supply to be somewhat limited. Of course, invention did not stand still, and nature, too, always provided compensations, and she had in this country, bestowed upon them a climate which encouraged the thought that whatever else they were short of, they would not be short of water. He remembered a certain cartoon in *Punch*, the moral of which was, "Conserve your rainfall," and he thought that Mr.

Pardoe's paper brought this point before them in another way, but none the less effectively and strongly. In this country, they had no large rivers, and the hills in the main part of the country were small, so that the water-shed did not give them any very great fall, as compared with the fall and flow which was found in, say, America or Switzerland. There was, however, no reason for them to neglect the sources of power, which they could find in the surplus rain which fell, and which flowed down the rivers in floods, and he believed that in the long run, when they were driven to it, they would consider the question of storage reservoirs in order to see whether they could adapt this source of power which nature gave them so generously.

Mr. W. H. HUNTER, in a communication regretting he was unable to be present, said some years ago he was concerned in the utilisation of water power by means of turbines, for a purpose to which such motors might well be more largely applied, viz., the opening and closing of the gates of the larger locks on the River Weaver Navigation. The turbines were of Schiele's, little known, but simple and effective type, and have now worked the gates of locks 43ft. wide without trouble, and with practically no repairs for a number of years.

Mr. J. A. SANER said the subject was particularly interesting to himself at the present time, owing to the fact that the Weaver Navigation Trustees were contemplating the use of the water on the river for electric purposes, so as to drive the machinery in the fitting shops in place of the present steam engine. The only kind of water power they had on the Weaver at present, with the exception of the turbines mentioned by Mr. Hunter, was the high-pressure hydraulic power at Anderton Lift and the dock cranes and hoists. Since he had been connected with the Weaver, he had always thought there was a large amount of

surplus water which might be utilised, but it was not until quite recently the Trustees had authorised him to ascertain whether it was possible to utilise it. Of course, in such a question a great many considerations were involved, and as the investigations had not gone very far he could not say much about them that night. The President had mentioned that the reason why water power was not fully utilised in England up to the present, was on account of the cheapness of coal; but he (Mr. Saner) thought another very strong reason was, that although there was abundance of rain its fall was so capricious as to considerably depreciate its value. He had for many years kept a regular record of the rainfall in the Weaver water-shed, and this record showed how very unequal the fall was in different periods.

The crowded state of the country largely prevented the storage of this rainfall from year to year; otherwise, they would be able to equalise the supply by means of reservoirs, and thus make greater use of the water available. Another cause for the non-adoption of water power was that many owners of land on the riverside each wanted their own portion of power, and could not agree to concentrate it in a central station and distribute it thence by other means. Personally, he thought there was an opening, in many cases, to concentrate the water power of a single river in central stations, and distribute it by means of electric wires instead of having water wheels at each mill. It was only since the development of electricity that this had become reasonably possible, but with Niagara as an example, he hoped it would not be long before similar arrangements were made in England. With regard to Mr. Higgins' plant, he would like to know whether he combined the high and low pressure water as in the hydrants fixed, in many places, for fire purposes. He had seen some of these in Hull several years ago, and they worked very efficiently in throwing a large jet of water, which was a combination of the high pressure from the

hydraulic station and the low-pressure water from the town mains.

As to the storage of flood water for use during dry seasons, he presumed the author's plan would be to erect sufficient turbine, or water-wheel power, to drive a full complement of dynamos during flood time, and that during that period he would be pumping, by means of the surplus power generated, water into the reservoir, and then utilise the water afterwards. The objections to this method seemed to him to be that there would be a very large capital expenditure in the first place, and that the steam engine, which would act as an auxiliary for dry seasons, could not be as economically used as the author thought, and for this reason: that during the dry season there would be no water for the steam engine to pump into the reservoir. He was not certain of having entirely grasped the author's meaning, but thought that the author contemplated using a steam engine to pump the water into a reservoir during the dry season. It was obvious, if the water were deficient above the weir, there would be none below it, especially in a river used for navigation or other purposes. As to the small turbines mentioned by Mr. Hunter, they certainly worked economically. He had been in charge of the Weaver for nine years, and they had scarcely cost anything in repairs during that time. An odd brass, or occasionally some of the pedestals, &c., or the valve-facings required repair, but the aggregate cost of repairs had been exceedingly small. Of course, they used a large amount of water compared with the power given off, but that was not such an important item on the river. As a matter of fact, the gates were opened in from $1\frac{1}{8}$ minute to about $1\frac{1}{2}$ minutes; the head of water varied from 11ft. 3in. to 8ft. 4in., and they had one as low as 6ft. 3in. Of course, in the lower head the turbines were larger than those for the higher pressures, but in all cases they worked well. In

conclusion, he thought that all present must be greatly indebted to the author for the trouble he had taken with the paper.

Mr. JAMES GÜNTHER observed that water power was used in this country to a much larger extent than many people were aware of. Most of the larger rivers, where there was any considerable amount of power, were already taken up, and where the water power was not utilised, it was either in districts where they could not well make use of it at present, or the cost of the necessary works, &c., was almost prohibitive. The cheapness of coal was also in some instances to be considered, and he had frequently met with cases where the question of utilising water power had come up, and it had been found impossible to compete with steam power on account of the low price of fuel. Another difficulty with large English rivers—which were usually in low-lying country—was the excessive variation in the water supply, which took place not only in the flow of water but also in the fall, the latter being often so much diminished during floods that the flood water power might be very little more (unless extra turbines were put to work) than the dry weather power. Storage, on a large scale, was impracticable in this country. On a given stream they might have, say, 4 to 12 mills within a considerable distance, with little or no fall between them, and to concentrate the water power of the stream in a large central station they would have to carry the channels or piping for miles. The cost of this would be prohibitive, and to it must also be added the expense of the necessary reservoirs, and most of our valleys did not permit of being made into reservoirs. In some exceptional cases, storage on a large scale might be practicable, but not generally in England. At the falls of Foyers there were several lakes which were being dammed up to a higher level in order to provide storage at a comparatively small cost. As regards water wheels, these were now practically

obsolete, and although large overshot wheels of the very best construction were quite capable of giving results equal to the best turbines, this was only in isolated instances. The amount of gearing required, the great momentum of the wheel and its consequent irregularity of motion under varying loads, were not adapted to modern high speed shafting and machinery. The author had referred to the construction of the water wheel. All those he had seen, such as the larger ones in cotton mills, were made with tension rods as arms. He did not remember any (except very small or inferior wheels) in which a separate spur wheel and heavy arms were used.

The statement that there was no best turbine was quite true. The type to be adopted should be regulated by the conditions of each particular case. This was a matter which was not always fully realised, and there were many instances where failure had resulted from the wrong turbine having been applied. With respect to the efficiency with a low-water supply, this was a point to which sufficient attention was not paid. There were many cases where, in the dry season, steam power had to be used to make up the deficiency in power, and the more efficient the turbine was when working with short water, the less was the amount of auxiliary steam power required. In one of the best American turbines, the efficiency, as tested at Holyoke, was about 82 % with full water, and only about 50 % with half water, so that a turbine of this particular type was not at all suitable for a variable water supply.

As to the impulse turbine, the author had stated that the circumferential velocity of the wheel was higher than that of the reaction type. This was no doubt an oversight on the author's part, as the circumferential velocity of an impulse turbine ranged between $0{\cdot}43\ \sqrt{2\,g\,H}$ and $0{\cdot}48\ \sqrt{2\,g\,H}$ and that of a reaction or pressure turbine usually between $0{\cdot}6\ \sqrt{2\,g\,H}$

and 0·68 $\sqrt{2\,g}$ H, $\sqrt{2\,g}$ H being the theoretical velocity of the water due to the total height of the fall.

With respect to the regulation of axial turbines by a leather band rolled up on a pair of rollers, this method was extensively adopted in France and Spain, but never to any extent in this country, as its action was too liable to be stopped by twigs or leaves getting in between the bands and rollers. The remarks as to regulation by a throttle valve in the supply or suction pipe are, of course, quite correct as regards regulation for a variable water supply, but there were many instances, especially in dealing with comparatively high falls and large powers, that when an automatic governor was required, so as to keep a perfectly uniform speed, the governor had to work upon a throttle valve, so as to ensure a quick action. In such cases, the throttle valve was only used for speed regulation, the adjustment for variable water supply being worked by hand and set from day to day.

For regulating mixed flow turbines the method by which a register gate was turned to alter the opening of the guide ports was very handy in connection with electric lighting, as a very small movement would close the turbine entirely, but this method was one of the most inefficient for dealing with a reduced supply, and should only be applied when a good part gate efficiency was no consideration. He agreed with the remarks on the angle of entrance in axial turbines varying according to the radius. In normally proportioned turbines the loss from this was negligable; but if the buckets were comparatively wide a special form of construction was adopted to avoid any loss from this cause. He might mention that where a high part gate efficiency was required, and the placing of an impulse turbine clear of the tail water would entail too much loss of head, this type could be arranged to run submerged by special construction, which practically meant that the air space was

occupied by the back of the vanes. If care be taken that the guide ports be free of the tail water, and air be let in at the top of the wheel, the turbine wheel would run submerged without appreciable loss of efficiency. The construction of such wheels was, however, somewhat complicated, and therefore not very often adopted. Six to twelve inches clearance between bottom of the wheel of an impulse turbine and tailwater was an excessive allowance on a low or moderate head, two to three inches being ample. Should local conditions render it necessary to place the wheel, in cases where the loss of fall from this cause be proportionately large, at a greater height than this, another type of turbine must be adopted.

The author had referred to the Geneva method, *i.e.*, pumping up a portion of the water by low fall turbines and pumps to a higher level, and thus forming a high-pressure service. He understood that in that particular instance, the primary object of the large turbines and pumps was to pump the water to a high level reservoir was purely for the usual town's water supply service. The expense of the dam, plant, reservoirs, &c., for this service was very great, and it was found that it would cost comparatively little more to put down extra turbines and pumps to pump the water into the same reservoirs, so as to provide power for a number of small industries. In this case, hydraulic transmission met the local circumstances better than electric distribution. The first idea here, therefore, was a town's water scheme, and this was afterwards extended to serve the double purpose, and the extra capital expenditure on the extra plant was more than recouped by the amount of the rental charged for the water for power purposes.

The utilisation of a small stream, insufficient in itself to develop the power required, to pump water continuously into reservoirs at a higher elevation, and then use the water so stored for a short period for electric lighting, would no doubt

be profitable in some cases, but in his opinion there are few places where the natural configuration of the ground lends itself to this plan, and the cost of the double plant would probably be much too great.

With reference to the lighting of small towns and villages by water power and electricity, there were certainly many places which could be so lit up, especially in North Wales and the Lake District. There were, however, so many different interests involved in this country as to often render this a difficult matter, even if there were a suitable water power near at hand. In Scotland, for instance, the fishery rights were a great source of trouble in this respect. He had had several cases brought before him, where it was proposed to light a village or house, and it had ultimately been found out that, in a dry season, the turbines would take all the water at a period when probably the salmon would be running up the rivers. On such occasions the run of the fish would be stopped, and consequently the riparian owners, who secured large rentals for the fisheries, would not allow the water to be taken for power purposes. This difficulty rarely occurred in England, but here, on the other hand, the rentals charged for water power were in many cases almost as much as the cost of coal, and this often prevented the water power being utilised. In foreign countries the state of affairs was usually quite different. He had come across a case in Spain where, he was informed, the use of the water was obtained from the Government for, he understood, little or nothing for the first 20 years, and after that period the rental was very low. The Government in such cases stipulated that the building of the mill must be commenced at once, and set to work within a reasonable period, say 12 to 18 months. In Mexico, again, it was usually considered by the Government that the benefits arising from the development of new industries fully justified them in allowing the water power to be utilised for little or nothing.

As he had previously remarked, although there was in this country a good deal of water power unutilised there was more used or partially used than many people thought, and frequently where it was not utilised there were many difficulties—quite unconnected with engineering—which at the present time prevented full benefit being derived from it.

The PRESIDENT, in moving that the best thanks of the meeting be given to Mr. Pardoe for his instructive and copious paper, observed that if water power were to be more generally adopted in this country they would have to form central stations. He might mention an instance which showed how it could be done. In the North Carolina district there was a range of mountains some distance from the coast, which provided a large number of streams, in which a regular flow was maintained, and here the cotton industry had taken a stand. The Peltzer Manufacturing Co. had three mills and wanted to erect another. They had plenty of valuable water power in their possession, but it was three miles from the proposed site. In order to utilise the water for the new mill they simply put down an installation of turbines, driving dynamos, and conveyed the whole of their power for the fourth mill by means of an electric cable. Such a method, in many cases, might be done in England.

Speaking on the general question, there was one thing tolerably certain, and that was that whenever this question of water power came to be considered it would have to be dealt with by the local authorities, who had the necessary legislative powers, and not by private companies. The riparian rights, which were the source of so much trouble, would have to be dealt with by bodies that could take a firm stand with reference to any proposed course of action, by virtue of their legislative powers, and only bodies of that sort could overcome opposition on the part of riparian owners. He was sure Mr. Pardoe's

paper would prove of permanent value in the records of the association.

Mr. T. DANIELS (Past-President) seconded the motion, observing that those of them who were not well acquainted with the subject would be considerably enlightened by the notes of Mr. Pardoe and the points raised in the discussion.

The resolution was carried with acclamation.

Mr. PARDOE, in reply, said that as regards the falling off in the coal supply, they would probably not see that for a long time to come. At the same time, it would have to be reckoned with in the future, and in this connection he might say that in the new fields that were being opened it appeared that the coal was very thin, which meant a large amount of waste work. In the Dover sinking, he believed that the best seam was only 3ft., and in some cases only 18in. seams were found, and they had to go very deep for that. He had often had in his mind the idea of combining a number of streams. The lead mining company which worked the Teesdale valley in Durham many years ago, had taken a number of small waterfalls on the upper portion of the Tees, and used them for driving small water-wheels driving pumps, which delivered into a system of high-pressure piping, the water being carried to the different parts required, and concentrated at the mills to develop the necessary power. That was an hydraulic central station method, but the thing could be done better electrically.

The utilisation of the Weaver mentioned by Mr. Saner was a very interesting point. The number of owners each wanting his portion of water power was undoubtedly a great drawback to the utilisation of water on a large scale. Each owner either required the use of it himself or asked a large rent for it, and the cost amounted to such a large sum that it would pay better

to carry coal a large distance than use the water which was at hand. All these rights had to be purchased or dealt with by legislative powers, if the power was to be concentrated as suggested by Mr. Saner.

With regard to Mr. Saner's suggestion, that if the motive power ran short, there would be no water to pump by auxiliary power, he (the author) might point out that a turbine did not consume the water, but only destroyed the head. This head might be anything conveniently obtainable, say 10ft., whilst the accumulator tank would be at a very great elevation, say 400ft., consequently the quantity of water pumped would not exceed $\frac{1}{40}$ part of the tail water, neglecting losses. Thus if the stream's flow fell to $\frac{1}{40}$ of the normal, a steam pump would still have sufficient water to store the required energy.

As to Mr. Higgins' machine, the plan mentioned was only his (the author's) suggestion, and might never even have been heard of by Mr. Higgins, who used the high-pressure water direct.

Respecting the storage of water at Geneva, his idea was not to put down turbines to utilise the flood flow, as the cost of *idle* works would be prohibitive. In electric lighting, for two or three hours a day about three or four hundred horse power might be needed, whilst for 10 or 15 hours, only about 10 or 12 HP would be necessary, and his idea was simply to utilise the power that would otherwise run to waste, and store it as suggested. The author knew several places where this system could be efficiently carried out, and where examination of the sites and the ordnance maps showed that a very short pipe line would suffice to reach a tank giving a head of upwards of 250ft., and in one or two cases, a head might be obtained of over 400ft. without any difficulty. It must be remembered that electric lighting work involved a very variable load, and the whole object of the proposed system of storage was to "compensate" the *load*

not the *stream*, the former being more easily done without great annual cost.

The cost of works was in many cases a great difficulty, and could only be dealt with after careful examination in each particular case. It could not be dealt with generally.

As to the Worcester works, he used the variation of supply there as a point which showed the desirability of storage, but did not mean to say that it was practicable in any or every case. This suggestion was to form a number of storage reservoirs, by securing legislative powers, and dealing with the whole watershed, thus compensating the stream as far as practicable, as suggested in connection with flood preventicn works on the Thames. They might get a flood once in 10 years that would swamp everything, and they could not provide storage room for such exceptional floods, but they could deal with ordinary floods with commercial advantage.

Regarding the test of wheels, he had not wished to make out a case against any particular wheel. He had not given the worst example.

The throttle for governing purposes had been used in a great many instances. He had seen one in a scheme carried out by Mr. Günther in Mexico, where it was used expressly for governing purposes, to obtain quick governing and save a very powerful governor, which would be sluggish in action. It was of no use as a regulator for short water. If they put a throttle into the supply-pipe the effect would be to reduce the effective head on the turbine and to maintain the same efficiency, irrespective of hydraulic loss at the valve, the speed of the turbine must be reduced to correspond with the effective head. He was aware that the impulse turbine could be made to work under water. It was then usually called, he believed, the "limit" turbine. The earliest Fourneyron turbines were, he believed, of this type.

With reference to the speed co-efficient of the re-action and impulse types of turbine, the author was obliged to Mr. Günther for pointing out the clerical error mentioned, which will be corrected in the final revision.

Respecting the construction of water wheels, his (the author's) observation was different from Mr. Günther's. Tension rods had often been used to stiffen the wheel, but his observation led him to believe it was not so common to drive from a toothed ring on the periphery as from a spur wheel on the axis.

At Geneva, the development of the scheme was, he believed, as Mr. Günther suggested. The system was first used for supplying water for the town, and then for supplying power to consumers by means of wire ropes. After a time, however, it was found that the spring water was being used for driving watchmakers' shops, in which cases the cost was not so important as extremely regular driving, and when the fresh water began to fail they used what might be termed rough water from a special supply under a great head for that purpose. At Zurich, he believed, the reservoir was put in for the express purpose of compensation. When the works were first put down the pressure on the supply pipes was maintained constant by first allowing the water to discharge through relief valves, spring or weight loaded, which was, however, found not to be a sufficiently-elastic arrangement, and a number of large air vessels were added to the system, the water being pumped into them and allowed to constantly escape to waste through the escape valves, The cushion of air in the vessels caused a uniform pressure. When the electric works were projected, however, it was found necessary to use this waste power. During the day, and the earlier part of the evening, the power was certainly nothing like equal to driving on the wire rope system, and also the electric works, and therefore the power was used which would otherwise run to waste at times of light load, when the

factories were closed, and the water was pumped into the high level reservoir.

With regard to fishery rights, Fort William was a case in point. The proposed site of the hydraulic works, he believed, had to be shifted, owing to the elaborate precautions required by the fishery owners. The large rents for water power also operated against its adoption, but in many cases it was practicable to use it, especially when only small power was needed.

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7 Plates follow illustrating this Paper.

UNIV. OF MICH.

ROPES AND ROPE DRIVING.

READ SATURDAY, 14TH NOVEMBER, 1896,

BY

MR. G. H. KENYON,

DUKINFIELD.

ROPE DRIVING.

To trace the history of Rope Driving, we should have to go far back beyond the days when Hero of Alexandria applied his discovery of steam power to rotary motion, which but for fanaticism, that great impeder of all progress, would centuries ago have deprived Watts of the glory of first invention.

We must search amongst the mounds of Nipur, which have recently proved that civilisation is older by 7,000 years than the world was supposed to be; and among the ruins of ancient Egypt to find the clumsy first forms of the potters' art. Comparing these with later but still early productions, when grace, beauty and utility first joined hands, we come to the time of the potters' wheel.

Still later the Hindoo wood turner begins to ply his trade, and may even to-day be seen sitting, as his ancestors have done for unknown ages, with tool in hand ready to catch the backward turn of his lathe, as his half naked attendant "see saws" at the ends of a rope whipped several times round the hub.

Or again come down to still later times in our own country, when the maiden of the household laid aside spindle and distaff to turn the spinning wheel, and submitted to the cognomen of "spinster" until the regulation quantity was spun off: and you

have the first principles of rope driving, from which the modern method of transmitting power has been evolved.

Arkwright after repeated experiment found it advisable to still adhere to this principle for driving the spindles of his spinning machine, a method which modern development has only sought to improve. Strange to say, some thirty years ago when the machinery of the mill occupied by this genius was undergoing re-construction, a system of rope transmission was found to be in full operation. How long this had existed we can only conjecture, but doubtless some obscure mechanic had conceived the idea of applying band driving to higher powers from the models around him, or it might have been the offspring of the master mind. At any rate the fact remains, notwithstanding the many who claim to be the foster parents of the system.

Turning from ancient history to more fruitful fields of research, it will be the pleasure of the writer to present to you such practical data bearing upon the transmission of power by ropes, as he has been able to glean from actual experience, after following most of the leading engineers of this, and other countries, for the last twenty-five years.

Here let him say once for all that he does not lay claim to any engineering skill, nor does he profess to make any pretensions of sifting and analyzing those profound theories, which are so persistently brought before the mechanical world. It is more his province to move in the wake of those who put their theories into practice, and take advantage of anything which is likely to prove of service to himself or friends.

POSITIVE MOTION.

For all practical purposes rope transmission may be regarded as positive, all things being equal, and in making calculations for speeds the supposition that slipping and consequent diminution of speed must of necessity enter into the equation, may be dismissed as scarcely worth consideration.

Cases have come under the writer's observation where ropes have supplanted spur gearing, and the machinery indicated loss of speed, but after the most careful investigation the main driving proved dead true to the decimal, and, in one instance, the pulleys were altered throughout the room affected, to meet the difficulty arising out of a misunderstanding of the initial speed.

Beyond this, and of supreme importance to power transmission, is the elasticity of rope driving, for the ropes themselves are very sensitive to any irregularity and act as a buffer between the initial and ultimate power, making back-lashing, the bane of gear driving, an unknown quantity. This quality is displayed to a remarkable extent in driving from gas engines, where the ropes may be seen readily yielding to every impulse, and just as readily recovering their normal tension without transmitting the shock to the machinery. If even a slight loss of power be admitted, the general effectiveness of ropes more than compensates for this, which is too often magnified beyond its merits, and can be reduced to such dimensions as will enable the engineer to ignore it entirely in actual practice.

It often happens that reports are received of ropes slipping, which on investigation prove to be quite groundless. Should there be any slip it can easily be detected by the heating of the pulley. Unless, then, pulley rims are unbearable to the touch from frictional heat, it may be taken for granted that there is no perceptible slipping. Stress should be laid upon this, because frictional heat appears to be rarely associated with slipping, and the evil is often declared to exist without its natural result.

In our works we have tried a ⅝in. diameter rope running over a loose pulley 18in. diameter, with grooves of an angle of 90 degrees, making 160 revolutions per minute, or a rope speed of about 720ft. per minute. This 18in. pulley was brought to a dead stand, and as the driver was only 12in. diameter, caused

the rope to run only about one-fourth its proper speed (say 180ft.), and in rather less than two minutes the paint on the inside of the rim blistered and smoked with the heat.

In the above-mentioned experiment, the heat was generated upon a portion only of the surface on account of the pulley being stationary, but when in motion the heat is more evenly distributed, so that it would not require a great amount of slip on a large driving pulley to set up heat sufficient to scorch the ropes.

What would be the result with a pulley 8ft. diameter, an acute groove, and a number of ropes of larger size, side by side, slipping at the rate of 60 feet per minute? and yet we have a case in hand at the present time, where an engineer has proved over and over again to his own satisfaction, that of four engines running side by side, the ropes are slipping on two of them at the rate of 60 feet per minute. This was said to be going on continuously, without producing the slightest heating of the pulleys, or injuring the rope in the least degree. If then, there is loss of speed on the machinery and no heat on the rim, the cause must be looked for elsewhere than in the rope chamber.

WEDGING ACTION.

To those who lay so much stress on wedging action, back tension, etc., and condemn the whole system accordingly, the following problems might prove interesting:—

Say, the wedging of a rope into its groove is stated as 50lbs. (an excessive estimate) and the centrifugal force for 1¼in. diameter travelling 4,700 feet, is 192lbs. What amount of power can be absorbed on extracting the rope after accomplishing its purpose? Or how can these opposing forces co-exist?

The resilience of a well made Cotton rope is such that perfect impact into the groove is impossible, even when the rope is forced into it under far greater pressure than is ever exerted in actual practice. This causes it to spring away

immediately the tension is withdrawn, even from a groove with sides at an angle of 25 degrees, and with the pulley stationary. How much less then would this presumed wedging action apply to grooves of 40 degrees with the pulleys running at a high rate of speed?

CONSTRUCTION OF GROOVES.

As in every other method, there are many points to be observed and enforced before the high tide mark of efficiency may be reached. First and foremost, the construction of the groove; and let it be said that simple as it may appear, the contest between one style and another has been keen in the extreme. The writer pleads guilty to splitting lances with many a "Hotspur" of the engineering faculty upon this very question, but has lived to see many who opposed him most bitterly, come round to his way of thinking.

The most effective style of groove is that with straight sides resting at an angle of about 40° and of sufficient depth to prevent the rope reaching the bottom, or the curve with which the groove terminates. On no account should grooves with curved sides be used, as it is impossible for ropes to bed themselves, and they become restless and roll round in the attempt. The consequence of this is, they do not last near as long, and are not as effective as when kept to one position, in order that they may work down to the shape of the groove.

The point mentioned above has been very much disputed. After careful comparison in some hundreds of cases, there remains no doubt in the writer's mind that a properly constructed rope fixed in its groove will last much longer than the same rope rolling round. Indeed it is computed that when ropes revolve their life is reduced at least by one-third. The effect of rolling is to cause the rope to wear down and eventually become too thin for the groove. There are some engineers who argue that a better grip is obtained from a rope rolling in the groove;

but a little reflection will shew the fallacy of this, as it is only possible for a circle placed between two flat surfaces to touch at a point on each side, whilst a rope which flattens to the shape of the groove gets a firmer hold of the pulley, and will as a matter of fact drive a much heavier weight than if it rolls round. We have selected from a large number of cases one which goes far to prove this contention.

The Cotton mill referred to was started in 1878. The ropes on the card room and some spinning rooms are fixed, have not required attention during all this time, and recent inspection proves them to be still in excellent condition. It is not, however, always possible to achieve this result even in properly constructed grooves, but this is chiefly owing to the fact that some engineers will insist upon ropes being fixed too slack for a start, so as to avoid heated journals. They have then no chance to pull themselves into their rightful position.

It need scarcely be said that the grooves of both driver and driven pulleys should be turned to the same template. Although there are numerous instances where ropes have been expected to do well when they were running in grooves of totally different make and size. Such difficulties however seldom arise when driving and driven pulleys are let out to the same firm.

On Plate 1, there are true reproductions of two pairs of grooves, Figs. A and B, for the same drive, one for the engine pulley and the other for the line shaft. The others are a few sketches taken from our groove book, which may some day be of historical interest. The diagram, Plate 2, illustrates a very simple method of setting out a groove.

The circle representing the diameter of the rope is first drawn, afterwards the centre lines. The chord of the arc A.B. then becomes the unit of future measurement, and points the centre for the bottom curve from the rope centre; this doubled, fixes the apex of the angle for the sides, which, when extended, intersect

the line C C drawn across the top of the rope, and point the centres for rounding off, besides deciding the thickness and the curve of the flanges. The angle will be seen to measure about 40 degrees and will come out exactly the same for every size of rope.

The opinion of the writer, however, is that the angle of the grooves should vary to some extent with the diameter of the ropes employed.

RELATIVE SIZE OF PULLEYS.

It is generally acknowledged that ropes should never be run upon pulleys of less than 30 times their own diameter. Although good Cotton ropes will coil in considerably less compass, yet it is always wise not to go below this limit, and err, if at all, in the direction of large size pulleys, as the repeated effort of compression and extension produces what is well expressed as "fatigue of material," when the elasticity is worked out. Ropes suffer more from this cause than any other.

The writer has come across numbers of cases where the relative diameters have not been more than half this, and ropes have been expected to do just as well as under more favourable circumstances.

The best results may be anticipated when the smallest pulley is 50 times the diameter of the rope.

There are Electrical Engineers who, for reasons best known to themselves, will persist in driving down upon pulleys out of all proportion to the size of the ropes employed, and, where difficulties arise, trot out some theory of their own, from which they argue that the fault lies in the ropes, that rope driving is a failure, and that they will be obliged to adopt direct driving.

In the writer's opinion, it is always advisable to consult with a thoroughly practical engineer respecting power transmission before submitting any scheme for the erection of electrical installations.

HORIZONTAL AND DOWN DRIVING.

Whilst it may be safe to advocate forward driving generally, *i.e.* with slack over the pulleys, the writer fears he will be compelled to renounce his faith in its supremacy for all conditions, and advocate another method for horizontal and down driving particularly, since recently comparing notes upon the many methods under consideration. He can bring to mind quite a number of cases where back driving has been adopted perforce with the best results. So smoothly do these ropes run that the idle side maintains the same equal curve without any perceptible deviation, whilst under similar conditions forward down driving has been anything but steady, and there has even been a difficulty in keeping the ropes in the grooves. Therefore, to secure effective down driving, back motion becomes almost a necessity. The great reason for this is that the centrifugal impetus given off by the driving pulley would, but for the check from its own endlessness, throw the rope far above the horizontal plane. These two opposing forces combine to create a wave-like motion which is intensified in proportion to its slackness or the erratic power applied, until, as before mentioned, there is danger of the ropes leaping the grooves and so threatening the safety of both machinery and attendant.

In forward driving, a rope curves in two opposite directions in descending from and ascending to the pulleys, whereas, in back driven ropes, the curve is in the same direction, and therefore renders no assistance whatever to undulatory motion. (See Plate 3.)

It is of course necessary to make the usual allowance for loss of frictional power upon the pulley between over and under driven ropes.

In upward driving (such as largely prevails in our Cotton mills) this tendency is effectually bridled by forcing the rope to run against, instead of over the pulley.

LONG CENTRES.

It is still a debatable question as to what distance unsupported ropes will convey power in a horizontal direction.

Judging from the admirable manner in which ropes are working at 90ft. centres, the writer would have little hesitation in fixing them at a still greater distance. The main conditions are, well-sustained journals, plenty of room to permit the sag running clear of obstruction, and a liberal allowance for extra weight of rope—back driving, of course, always understood.

The limit of endurance would be the same in any diameter of rope, as specific gravity and tensile strength are the same in proportion to the sectional area.

For forward driving, much depends upon the diameter of the pulleys being sufficient to lift the outgoing from the incoming part of the rope.

In order to dispense with mathematical theorem when approximating the sag of the rope, we apply a very simple rule as indicated on Plate 4.

For back driving, draw the arc F F from the centre A, and arc C C from centre B. Where these cross, is the centre of the curve tangent with the lower circumferences of the circles.

For forward driving, draw the arc E E from the centre A, and the arc D D from the centre B. Where these intersect each other, is the centre for the curve tangent with the upper circumferences.

Working this diagram out to its logical conclusion, it will be seen that when the circles touch each other the upper curve ceases.

It may be added that there is not sufficient depth on the sheet to show the position of the curve centres, but probably this description will be understood.

This diagram will also be found useful whenever it is necessary to pierce through walls, and in finding the depths of drives;

and although it does not represent the catenary curve it is near enough for general purposes.

VERTICAL DRIVING.

Pulleys fixed on the same vertical line may be successfully driven by putting on extra ropes, as the weight of the rope tends to fall out of the groove instead of into it. In this case, general efficiency depends greatly upon the elasticity of the rope.

CONTINUOUS DRIVING.

In America, Germany, and to a very slight extent in this Country, an attempt has been made to push a system of rope driving known as the continuous drive, by which the power is transmitted through a single rope wound round the pulleys. The advocates of this system claim for it equality of tension, one splice to each drive, and greater general efficiency. It is a matter of surprise that such a system could obtain any hold at all, and it speaks well for the general run of engineers in this country, that it has made no headway, for a very little consideration will prove that any advantage claimed for the continuous, over the separate rope rests upon a very slender foundation.

As to equality of tension, this is a myth; for if anyone will stand alongside an engine worked by a continuous rope, it will be quite easy to count the number of grooves by watching the slack of the rope travelling from groove to groove. This means that there is a continuous leaping of the rope on its passage round the pulleys.

It will be obvious that to depend upon a single splice in a rope is to forego one of the main advantages possessed by ropes over belts. If a splice gives way on a continuous drive the machinery must at once be stopped, and the danger of entanglement and consequent serious damage in the case of a sudden drawing of the splice becomes a certainty. One advocate of this system refused to admit the danger mentioned until

his jockey pulley was caught by a roving splice and flung through the roof, much to the alarm and danger of everyone in the vicinity of the power station.

When the question of durability is considered whether as relating to the pulleys or ropes, then the advisability of using separate ropes is more than ever apparent. In the first place, the fact that the grooves must be out of line with each other prevent the ropes entering in the usual way but forces them aside. This deviation from the straight line directs the rope over the sharp edge of the groove. Then again the rope has to be brought back across the full width of the pulley and must have a jockey to guide it, as shown on Plate 5, causing the bending and straightening of the rope in another direction. Or by a carrier somewhat larger than the driven pulley, and fixed behind it, as shown on Plate 6.

There are other and more elaborate contrivances pressed into the service, each designed to place continuous driving far above every other method; but all open to the grave objections above enumerated.

The rope has also to be kept very tight, and at the point of contact so great is the pressure that in a very short time the grooves begin to wear. In one case it was discovered that after transmitting 1,000 HP for a period of three years the side of the groove upon which the rope entered was worn away to a very appreciable extent. If then the damage to the groove is so apparent, that done to the rope is greater still, and it will be difficult to design any system of driving which would be more destructive.

It will be readily seen that all these extra contortions break up the rope very rapidly and make frequent renewals a matter of necessity. None of these disadvantages apply to ropes fixed in the ordinary way, for it is most unlikely that in the case of twenty or more ropes running side by side, more than one splice will

give way at once, which means that if a rope gives out it can be put on one side and the remainder left to do the work until such time as may be convenient for replacement.

With respect to equality of tension. One rope hanging rather lower than the other makes so little difference that it may be treated as a negligable quantity, for on careful measurement it will be found that a rope which appears very slack as compared with its neighbours is not more than a few inches different.

The diagram Plate 7 will best illustrate this contention. Taking the straight line from the centres as representing 30ft., No. 1 curve is only 30ft. 3in., No. 2 30ft. 9in., No. 3 31ft. 6in., and No. 4 32ft. 6in.

The depressions, therefore, of these curves appear very much greater than the difference in their actual length suggests.

CROSS DRIVING.

Up to this point, the question of rope driving has been treated as relating only to pulleys turning in the same direction.

Ropes, however, may be as successfully applied to cross driving, with certain reservations, just as in the case of belts, gaining in frictional power, inasmuch as they cover more pulley surface, but at the expense of the ropes on account of continual contact in passing each other. To avoid the latter contingency as much as possible the pitch of the groove should be twice the usual distance, there being actually double the number of ropes at the crossing points, see Plate 8, Fig. 1.

The ropes should also be crossed alternate ways in order that couplets may travel the same path in agreement and share alike the inevitable rubbing, as shown on Plate 9.

ROPE AND SPUR GEARING COMBINED.

The difficulty of driving with ropes and spurs together, *i.e.*, from one to the other either way, appears to be the result of backlashing, spurs being too rigid to yield to the more definite

action of the ropes, which causes them to oscillate from side to side and often fly off the pulleys.

It is a mistake to suppose that tightening will obviate these difficulties. This tends only to prevent reciprocal action, and we have known cases where teeth have been stripped as a result of tight ropes. Under such conditions, slack ropes are not only necessary but they should be fixed at different tensions in order to break the harmony without interfering with general efficiency. Each rope will then vibrate to a different rhythm, unless, which is not likely, the measure so arranges itself that unison of action is occasionally produced.

Plate 7 shows this difference in tension somewhat exaggerated.

ROPE SPEED AND POWER.

Dismissing from our minds the vexed question of centrifugal force and the somewhat complex process of reasoning by which its effect upon high speed is supposed to be ascertained, it may be laid down as a safe rule to follow that a good cotton rope, 1¼in. diameter, running at 1,000 feet per minute will comfortably transmit 10 HP, and that this power increases or diminishes in the same ratio as the speed. You may therefore expect this size of rope running at 7,000 feet per minute to transmit 70 HP. Some of our ropes are, however, transmitting 98 HP each at a speed of 7,040 feet per minute, and on one occasion, owing to an accident to its fellow, double this power was for a time transmitted through a single 1¼in. rope.

We understand that an engine is now in process of construction which is designed for a rope speed of 8,000 feet per minute, or rather over 90 miles per hour, and is to transmit 80 HP per rope. Even this may ere long be exceeded. At any rate, it appears that the speed limit has not yet been reached.

Taking the above relative size, speed, and power for granted, it now only remains to calculate the power of other sizes from

the sectional area, which may always be regarded as that of a circle.

A rope 1½in. diameter will then transmit 7·84 HP and 1¼in. diameter 5·1 HP per 1,000 feet of speed.

THIN v. THICK ROPES.

Referring to the much contested question of the relative efficiency of thin and thick ropes, actual practice contradicts the oft advanced theory that ropes, say from 1in. to 1½in. diameter, may be run with greater advantage than the thicker sizes, allowing the same relative diameter of pulleys.

In the matter of durability thick ropes certainly take the lead, and this may be accounted for by the fact that their wearing surface is greater in proportion to the sectional area: *e.g.* we will suppose that a 2in. dia. rope is worn ¼in. of an inch all round. This would bring down its actual strength to 1¾in. diameter only, or as 64 is to 49. The same chafing on a 1in. rope would reduce its strength to ¾in. dia. rope, or as 64 is to 36. It may also be mentioned that this fraying is far more pronounced on small than large ropes. Two inch ropes however look rather clumsy, are not easily handled in splicing, and necessitate large pulleys. This may to some extent account for 1⅝in. and 1¾in. becoming favourite sizes.

GUIDE PULLEYS.

There is scarcely an angle or position of shaft to shaft from which power may not be transmitted by means of ropes and guide pulleys. Take, for instance, the intricate arrangement for driving a spinning mule or travelling crane.

It must, however, be noted that every additional pulley beyond the necessary driver and driven takes from the durability of the rope, not only on account of extra friction but from strain and contortion. In consequence of this, the average life of a crane rope is scarcely a tithe that of the ordinary driving rope.

The penalties of indirect driving may, however, be considerably mitigated by using large and well-fitted guide pulleys, made as light as possible consistent with strength, having rounded grooves a trifle wider than the diameter of the rope, and of sufficient depth to bury it, as it is far better for the rope to lie well on the carrier rather than merely touch it in passing. See Fig. 2, Plate 8.

Many cases have come to the writer's knowledge where small guide pulleys and even rollers have been used to prevent ropes striking against, or for lifting them over beams and other obstructions. The effect of a rope 1⅝in. diameter, running at 3,000ft. per minute, either intermittently or constantly, upon a pulley 18in. diameter, must be disastrous, and if this be reduced to a 4in. roller the result will be still more so. The best way out of this difficulty, if the obstruction is irremovable and space will permit, is to fix an intermediate shaft and pulley with double the required number of grooves for the ropes, and drive forward.

FAST AND LOOSE PULLEYS.

The advantages claimed for main driving apply also, but in a more marked degree, to secondary motions.

By an arrangement of fast and loose pulleys such as is shown on Plate 10, we are enabled to transmit power from the second motion shaft direct to the machinery with small ropes or bands, and so dispense with the comparatively clumsy system of belt driving.

This patented combination is the outcome of almost continuous experiment upon frictions, clutches and the like, and is in operation throughout our works; for as may be supposed, we naturally supplant belts wherever practicable. For driving delicate machinery where a quick start and knock off, as in the case of mules or looms is necessary, this system is most

effective. As will be seen, Fig. 1, Plate 10, the traverse from one pulley to another is only a trifle over the width of the band itself, which is moved very readily with an ordinary strap shifter or fork.

For gradual starting, as in the case of heavy machinery a shallow intermediate groove is turned in the fast pulley upon which the band gains a revolution or two before falling into its working groove (Fig. 2, Plate 10). In this case the traverse is increased, but without affecting in the least the general efficiency of the band.

In strap driving it is generally necessary to have the driving pulley equal in width to both fast and loose pulleys, which means that a 3in. belt would occupy 6in. of shaft space, whereas a band ½in. diameter would transmit the same power more effectually and only occupy the space of a suitable one grooved twitch pulley.

Nor does the machinery require setting with the same exactness in relation to the shafting, as bands will run well even when shafts are out of truth with each other.

One instance to demonstrate the positive action of ropes as compared with belts. Some time ago we prevailed upon one of our engineering friends to use our fast and loose pulleys for the overhead gearing of one of his boring lathes. Previously, his workman was much troubled with the belt slipping, and occasionally working off, but since applying the rope there has been no repetition of the trouble and the lathe does it work without the slightest hesitation.

In this case a ¾in. rope was used to replace a 3in. belt and works with slack below the pulleys.

As a matter of general economy, it may be said that ropes to transmit an equal power may be purchased at about one-fourth the cost of belting.

Ropes for this purpose could be supplied ready spliced. A spare one might be tied over the shaft against accident and replaced whenever it was convenient to lift the journals.

Plate 11 illustrates the application of fast and loose rope pulleys to ordinary machinery. In this instance, with the shafts at right angles to each other, no carrier pulleys being used.

DRIVING-ROPES.

Now allow your essayist to leave the general mechanical bearings of rope driving and invite your attention to another, and, to him, more congenial phase of the question—the rope itself.

Although etiquette forbids him mentioning a great many things which commercial instinct naturally suggest, he can scarcely pass over this part of the subject without giving some little personal experience. He will, however, endeavour to keep well within the bounds of unbiassed criticism, and upon the broad lines of the principles involved.

To fully discuss the question of the ropes themselves would require a special paper, as there is no part of rope driving upon which greater mistakes are made than in this department.

MATERIAL.

It would be impossible to enumerate the various classes of material which have been used in the manufacture of ropes. They may, however, be roughly divided under the two heads of Hemp and Cotton.

As Belfast and Dundee jointly claim the honour of first introducing rope driving to any large extent, there need be little wonder that Manilla secured the first place when the system was yet young; until Lancashire began to see that it was worth bringing up to maturity, and applied the reasoning that as Hemp of any kind would not successfully drive spinning machinery, it was only a question of the application of cotton to greater powers.

As it is most difficult to explain any material without handling the same, a sample of ordinary Manilla rope is here submitted, which, upon examination, you will find is of so harsh and obstinate a nature that the fibres will not close together. The strands therefore retain their roundness, and although showing some little internal pinch there is no real impact with each other, therefore instead of the fibres expanding and contracting *en masse* when bending over the pulleys, the individual strands act independently of each other and set up internal friction, so that after working only for a short period the inside will be found reduced to a fine powder. The rope naturally extends as this grinding progresses, and requires frequent tightening, which brings it up to the required tension for the time being, much reduced in diameter, and still more rigid with frequent extension, from which it has not the power to recover; rendering it of course less suitable for the purpose, until it has to be replaced, sometimes even when it is apparently in good condition externally.

Those of you who have visited a rope race where Manilla is used, will doubtless have noticed unmistakable evidence of friction both against the grooves and within the ropes themselves, by the distinct whistling sound emitted when the ropes are bending over the pulleys.

The same demerits apply substantially to all classes of hemp. The fibres of Italian hemp are the finest known to this family next to flax itself, and are exceedingly long and strong; but even these lack at least one essential to efficient driving, *i.e.*, resilience.

It may be admitted that twine laid Manilla ropes will do moderately well when all the conditions are favourable, but this is only a matter of degree, and we must fall back upon comparison in dealing with the question of general efficiency.

COTTON.

Whatever new material may be discovered in the future (and we have had new fibres only recently submitted to us for experiment) the writer knows of none which up to now have even approached, let alone superseded cotton for this purpose, for it is both strong, durable, and pliant, yielding readily to the shape of both pulley and groove, and quickly recovering its normal tension after every wrench and strain.

This being now a generally accepted axiom, it remains only for us to select from the two great classes of cotton known to commerce as American and Egyptian.

The fine, strong, silky staple of Egyptian may well recommend itself before its coarser grained American rival, and has been extensively used for the purpose; but early on in the contest we theorised that these very qualities might or might not be advantageous for driving ropes. We then set about experimenting upon both in the only feasible manner which suggested itself, *i.e.*, by running them together under precisely the same conditions and awaiting patiently the issue, which under ordinary circumstances meant a period of about 15 years, had we not been favoured with an opportunity of deciding the matter in three or four years, on this wise :—

We came to an arrangement with the owners of three large cotton mills, engaged upon spinning fine Egyptian yarns, that they should supply us with the best quality procurable spun down to a certain counts, which we would manufacture into driving ropes and run side by side with those made from equal spinnings of American.

A drive was selected for this test on account of its abnormally high speed, from which the ropes were periodically removed and used upon slower speed engines. These ropes were therefore put to work and after the usual period had elapsed were removed. Pieces of equal length were then taken from the best part of

each rope, thoroughly dissected thread by thread, they in turn tested, counted, and weighed, the whole as against the damaged threads (a most tedious process), with the result that the American proved to be in 12 % better condition than the Egyptian. We were scarcely prepared for this, what we most expected was that there would be a fair recompense for the extra cost of Egyptian, and all things considered they would come out about equal.

MAKE AND STRENGTH OF ROPE.

The general principle of making ropes from textile material cannot be better described than by saying that the whole mass of fibres is held together by means of twist, which in the case of Cotton begins in the card room and ends with the completed rope. Fine yarns are formed into threads and they into strands by the same agency. The strands are again rolled together in the opposite direction, thus locking them and checking the tendency to rove.

These strands may be few or many according as discretion may dictate, but as a general rule they are not less than three or more than seven.

The strand diagrams (Plate 12) may be well represented by as many circles showing the principle upon which they group themselves. External pressure however acts upon the inner portion of the rope, and in the case of seven strands makes an irregular hexagon of the centre.

It needs but little consideration to discover that the strands of a rope made in this manner cannot act in unison, and that the strain consequent upon the contraction and extension of the body of the rope must be more severely felt by the centre than by the six outer strands, which are spirally twisted around it.

The spiral action, like that of a spring with a cord held tight through the centre, is thus most effectually hindered, and the very essence of efficiency destroyed. Beyond this, the more

strands there are, and the more rigid the rope. It therefore stands to reason more effort must be exerted in bending round the pulleys.

The same arguments also apply to five strand ropes, (or more correctly, four strands with a core down the centre); with this exception, the centre of a seven strand rope contains one-seventh part of the total material employed, whereas, the heart of a four-strand is only of sufficient thickness to fill up the central gap of the circles, or say one-fortieth part of the whole bulk. While therefore offering less resistance to the spiral action it is also considerably weaker than the rest of the rope, and having to sustain the brunt of the direct strain is quickly broken up. The strands, then, in their attempt to fill up the vacancy formed by the withdrawing of the broken pieces, push one another out of position; thus producing what is technically known as "riding" strands. The rope then becomes distorted from its otherwise graceful shape, and presents lumpy irregularities to chafe against the grooves.

More perfect rotundity and consequent better filling of the grooves, is the favourite argument of the advocates of these two makes of ropes; but if, as the writer has endeavoured to make out, a rope is better when it assumes the shape of the grove, then this theory falls to the ground and need not be further discussed.

Very early in our connection with rope driving, we advocated the use of three-strand ropes only, on the principle that the more sub-division of the general body the more also is the frictional surface divided. Again the centre gap of three circles is so comparatively small that it requires but little compression to fill it up without resorting to the troublesome core.

Much to the writer's surprise, a friend who is rather strong on a greater number of strands for main driving will now only have three-strand ropes upon his travelling crane, for as he avers,

they offer more resistance to the enormous strain put upon them. If, then, three-strand ropes will do better than any other when the wear and tear is so great, why should not the same virtues apply to the general economy of rope driving?

Going back again to machinery driving, in how many of our cotton mills will you find anything but three-strand rim or scroll band?

Beyond all this, the breaking strain of three-strand ropes is higher than any other number. In order to put this assertion beyond doubt we have very carefully compared the attested reports on cotton ropes issued by Messrs, David Kirkaldy & Son, of London, and now submit the following as representing the most impartial examples:—

Four strand cotton rope 1¼in. diameter, total breaking strain 9,204lbs., strength per fathom weight 3,409lbs. Three strand cotton rope 1¼in. diameter, total breaking strain 12,017lbs., strength per fathom weight 4,202lbs. This, therefore, declares the three strand rope to be the strongest by 30%.

As the general efficiency of high speed transmission depends greatly upon the capability of the rope to withstand the increasing strain, and the limit of endurance decides also the limit of velocity, so the breaking strain of a rope is by no means the unimportant item some endeavour to make it.

If, then, every thread of a three-strand rope is so laid as to incorporate itself into the general spiral system without deviation from its track; if they are equal in counts, number, and tension throughout their entire length, and are of good quality, the writer cannot but think that such a rope is as near perfection as possible. Plate 13 illustrates a rope made on this method, which has been designated the Patent Inter-stranded Rope, because of its peculiar construction. From this it will be seen that when the outer layer of threads is worn through there is still a complete rope within, until it is reduced to the last section.

This method again insures an almost incredible increase in strength.

Not long ago we were supplied by the War Office with an ordinary three strand sample to be tested against our patent inter-stranded rope, with the result that Kirkaldy declared the War Office rope to break at 1,258lbs., or 4,838lbs. per fathom weight, whilst the inter-stranded rope broke at 1,667lbs., or 6,412lbs. per fathom weight, giving 32½ % in favour of the latter make. Both were made the same diameter (viz., ⅝in.) and of superior American cotton.

Anxious also to test the accuracy of our theory that as yarn spun into coarse counts from a higher mixing of cotton would stand a greater tension than if drawn out to its full extent, and that this would be felt in the rope itself, we also sent a sample made from yarn spun twelve counts finer. The breaking strain of this proved to be 1,579lbs. and strength per fathom weight 5,639lbs., or 5 % less than the sixteens above mentioned.

It may therefore be taken for granted that it is not advisable to make driving ropes from very fine yarns.

In the three tests above mentioned we were restricted to a small diameter, but after comparing the stress per fathom weight, which should come out about the same for every size, provided they are equal in make and quality, and making every allowance for the fact that small ropes may be tested with greater accuracy than large ones, the enormous strength secured to ropes made on this method will be all the more apparent.

SPLICING AND FIXING OF ROPES.

The splicing of driving ropes demands more attention than it usually receives. The difference between a fairly good splice and one made by a first-class workman, often means doubling the life of the rope. Although it is expensive to send men long distances, the writer is convinced that for any large contract it

would pay to send a thoroughly competent man a few thousand miles in preference to having the ropes indifferently spliced.

It is impossible short of ocular demonstration to give a proper conception of the process, but Plate 14 may help a little towards this end. Fig. 1 shows the ends lashed together half way in the length allowed. Fig. 2, the unravelling of the strand from one side to be re-inserted from the other. Fig. 3, the strands reduced (by stripping the outer shell) ready for working in with the marline spike. Fig. 4 requires only the projecting ends cutting off to complete the splicing as shown in Fig. 5, from which it will be seen that the difference between the spliced and unspliced part of the rope is almost imperceptible, and when in motion cannot be detected.

Long splicings are usually made 72 diameters of the rope or say 10ft. 6in. for 1¼in. This quantity is actually consumed, and should be accounted for in taking measurements.

The fixing of ropes would be much more easily accomplished if the shafts and bearings of driving pulleys were always made sufficiently strong to withstand the strain of forcing the ropes over the pulleys and into the grooves.

The bearings should not be too far away from the pulleys, but it is quite sufficient to allow a clearance of say three-rope diameters on each side to allow the ropes free play. The same applies to the fixing of counter pulleys of more than two grooves. For one or two grooves this clearance on one side only would be sufficient.

Plenty of working space between the large pulley and the wall is of course an undoubted advantage to the splicer, and may often prevent serious accident from entanglement.

RE-LUBRICATION OF ROPES.

The little lubrication required for driving ropes is best put on during the making, in order that the strands may receive a

thin coating all round. Any supposed lubrication within the strands serves no useful purpose.

It is also a mistake to suppose that ropes require almost constant attention in this matter.

The writer has known not a few cases where ropes have been so covered with greasy compounds as to partially fill the grooves, with the natural result that the ropes have commenced slipping. In such cases he has recommended the attendant to clear out the grooves and apply a liberal dose of whiting to the rope for the purpose of drying up the superfluous grease.

If ropes are re-lubricated at all, once a year is usually sufficient, and even then they should only be smeared just to lay the broken fibres, which may be seen on any cotton rope after running a while, but which do not penetrate below the surface and are no real detriment.

Plumbago is undoubtedly the best lubricant, but requires something to hold it together on account of its dusty nature. Good domestic soap and a little tallow will suffice for this purpose. It is best applied when set moderately hard, so as not to go on too thick. Avoid all greasy compositions which are likely to penetrate. They only tend to soften the fibres and reduce the rope to a sop.

DISCUSSION.

Mr. GEORGE SAXON said he was surprised to hear that Kirkaldy gave the greatest strength to the three-strand rope. From an extract out of Nasmith's "Student's Cotton-Spinning" he noticed that one celebrated rope-maker adhered very firmly to the four-strand rope, and stated—apparently from Kirkaldy's tests—that it was the more efficient. He (Mr. Saxon) quite agreed with the author that the three-strand was better than the four-strand,

owing to the construction. In the latter, the core that was put inside to make up the space had a detrimental effect upon the rope. In practice, Kirkaldy's test might come out practically the same as a three-strand rope, but, in his opinion, in actual working it had only half the life of a three-strand rope. The core crumbled up, and caused the rope to collapse, so that its life was very much shortened. At all events, his firm's experience was undoubtedly in favour of the three-strand rope.

As to American and Egyptian cotton, he quite agreed that the former was the best for ropes. The Egyptian cotton might be finer, and have certain other qualities such as pliability, &c., but, to his mind, the American material maintained fully the percentage of superiority named by the author.

With regard to splicing, it was a great mistake to let workmen who did not thoroughly understand the operation to deal with this matter. In such cases, if the rope had very much work to do, it would soon come to pieces. The best plan, if they had not a really efficient man about, was to let the rope-maker send to do the splicing, and they would then obtain a long life for the splice.

The inter-stranded rope appeared to be a very good and improved method, which, in his opinion, would increase the life of the cotton-rope.

Mr. C. N. Pickworth said he should like to ask Mr. Kenyon's opinion as to the cause of ropes rotating on their axes. Why was it that in one set of ropes some would turn while others flatten at the sides and never attempted to turn? It was sometimes said that want of alignment of the two sets of pulley grooves was the reason, but this should cause the whole set to turn. By others, it was held that axial rotation was caused by the slight twisting and untwisting of the rope as it was alternately subjected to the tight and slack side tensions.

There seemed to be a difference of opinion as to the relative durability of rotating and non-rotating ropes. Mr. Kenyon's statement that the life of a rope was reduced one-third was the highest estimate of loss from this cause he had yet met with, and he should like to know if others had noticed so great a loss. If so, it was evident that ropes must be prevented from turning at all hazards. He thought the rope which did not turn should wear longest; not so much by reason of the lessened exterior wear as in consequence of the bending always taking place in one direction. They knew that reverse bending in the case of wire ropes shortened their lives by some 15%, and it was reasonable to suppose that the effect in cotton or manilla ropes would be somewhat analogous.

Regarding the statement that electrical engineers frequently used pulleys much too small for the size of the rope, was not this due to the high speed of rotation which the dynamos required? If the ropes were run at their most efficient speed—about 5,000 feet per minute—it might be shown that, if pulleys of 80 rope diameters were to be used, no larger rope than 1in. should be employed for a dynamo making 600 revolutions per minute, while for 800 revolutions $\frac{3}{4}$in. was the largest admissible size under these conditions. Of course, he was not defending the use of small pulleys—far from it; but it seemed to him that, while much was due to ignorance of the proper working conditions, a good deal was traceable to an attempt to effect a compromise between conflicting factors.

The continuous system of driving, which Mr. Kenyon so unreservedly condemned, was being largely adopted in America. For small powers, where corners had to be turned and shafting driven at various angles, the system appeared to have advantages. It was also suitable for vertical driving. The fatal objection to it was the total stoppage which a breakdown caused.

He was sorry Mr. Kenyon had not given some particulars of the strength of ropes of cotton and manilla. From data he had collected he found that an effective stress of about 200lb. per square inch, which might be more conveniently expressed as 160 times the square of the nominal rope diameter was in accordance with the best modern practice.

Mr. F. F. BENNETT said that he had not contemplated speaking or taking part in the discussion that evening, but as an electrical engineer he could not allow the statement of Mr. Kenyon, which had reflected on that body, to pass unchallenged.

As a matter of fact he knew of very few cases in electric lighting where the driven pulley was below the driving pulley.

The majority of provincial central stations adopted the rope driven plants with every success, but the centres of driving and driven pulleys were horizontal in all cases that had come under his notice.

He was not much acquainted with the London systems, so would not speak for them. All he knew was that provincial electrical engineers had nothing to learn from London electrical engineers, and thought it was rather *vice-versa*.

Of course there were central stations in densely-populated towns, where space was a great desideratum, and direct coupled plants had been installed, the extra annual cost of rnnning not being of sufficient importance as to justify the renting or purchasing the large amount of extra space that rope driven plants would entail, but in the provinces these stations were the exception and not the rule.

As to the economy of rope driven over direct driving there could be no question. At Burnley, with good compound condensing engines, horizontally driven dynamos by ropes, the coal cost was only ·33d. (less than a halfpenny) for producing a Board of Trade unit.

Mr. ALFRED SAXON said in designing rope-drives he did not think it was the practice to call in the rope-maker for consultation, but if all rope-making firms had studied the subject as much as Messrs. Kenyon this would prove an advantage.

He had heard the late President of the Mechanical Engineers (Prof. Kennedy) refer to the barbarous methods of driving adopted in Lancashire, such as rope-driving, &c. No doubt there were some losses, but gentlemen present would scarcely accept the professor's statement.

As to the angle of grooves, they would find strenuous advocates of both one groove and the other, but he thought a little range might be allowed. Taking angles from 40 to 45 degrees, a variation between these two angles was quite permissible in good practice. For the past ten years his firm had split the difference and taken 42½ degrees as the average.

He certainly agreed with the author about straight sides being the best in grooves. The curved sides had, as stated, the disadvantage of tending to produce that rotary creeping of the rope which was evidently not conducive to longevity. As to the form of groove submitted in Plate 2—where the curve was struck with a radius C B from the centre, and one of the rounding points—the author showed the upper part of the groove not in contact with the rope struck with a radius. In his (Mr. Saxon's) opinion this was only necessary where they wanted a narrow pitch of grooves. If they carried the groove straight out without adopting the curve in the upper portion, they would have a wider pitch, but that would be the only disadvantage.

As to the relative size of pulleys, and the recommendation to have the smaller pulleys 50 times the diameter of the rope, he had made some calculations on this point, and found that the conditions affecting the size of pulleys varied greatly according to the case with which they had to deal. If they took a building

where they were tied for room, or a case where there was a high speed of shafting, it was almost impossible to use pulleys of such a large diameter, and in such cases as counter driving inside mills the difference between a driving pulley 30 times the rope diameter and another 50 times, and the proportionate increase in the size of the drivers, would frequently involve a very expensive arrangement, and unless the customer saw the advantages of one size over the other he would not adopt the plant on account of the expense. There were a number of things that ought to guide them in the matter. One consideration was whether they were unrestricted in the question of cost in doing the best possible job, or were they doing something which, in their own opinion, would give the most satisfactory results in proportion to the expense incurred. For a main rope drive he thought the size named of 50 times was advisable, because there was such a big difference between the diameter of driver and driven pulley; but in counter driving, where the difference was not so large, he could not go to the extent recommended by the author in the majority of cases. He agreed with the author's remarks on horizontal and down-driving; and, as to long centres, he remembered a case where his firm had arranged a very long drive, but, so far as he could recollect, jockey pulleys had to be put in. It was a forward drive, and worked very well in driving a paper mill.

Mr. Kenyon had not told them much about rope-driving when shafts were not parallel. This was a point which puzzled engineers occasionally. It was difficult to guide a number of ropes when the shafts were not parallel. With a single rope there was not so much trouble, as they could take it in any corner throughout the whole building, but with a number of ropes, when the shafts were not parallel, it was different. The question arose as to what form of groove was the best and how far out of line could they be permitted to go.

With regard to the size of main-driving ropes, no doubt the remarks as to wear were correct; but at the same time the practice, at any rate in Lancashire, was to not use ropes above 1½in. diameter, and such ropes were large enough for all practical purposes, if they did not give them too much to do.

The patent driving system described by the author seemed to be a good thing, on paper, but he was afraid in practice the plan of having ropes ready spliced, for replacing when the journals would have to be lifted, would be awkward.

With regard to manilla ropes, he had visited a mill that had been working six years, where these were used on a driving pulley 30ft. and driven pulleys 8ft. diameter, and was informed that they had worked very well, the manager adding that, when necessary, he would put manilla ropes in again.

The writer had referred to persons expecting certain results, while working with badly-shaped grooves. Perhaps he could tell them what the results were, and whether they came up to expectations.

He would also like to know how the author arrived at the conclusion that American ropes were 12% better than Egyptian, and whether, as they would assume from the paper, the writer's firm had themselves adopted the American yarns for rope-making.

Mr. JOHN TAYLOR said no doubt driving ropes would not be easily superseded, as they performed a useful service, very satisfactorily and economically, if they were looked after with care. The largest application of rope driving was for the rims of self-acting mules, and it was the successful results obtained in that direction which encouraged other people to adopt the system.

Mr. SAMUEL BOSWELL asked which was the best way of holding a rope in order to break it. He had tried various methods, but had not been able to effect a satisfactory break.

The PRESIDENT (Mr. J. Nasmith) said, with regard to the system found in Arkwright's shop, he should certainly assign it rather to the "obscure mechanic" than to the so-called "master-mind." His view on the Arkwright question was that Sir Richard was no genius other than a commercial one, and he must enter his protest against the description of him as a "master-mind."

On the question of revolving ropes, he might observe that when people talked about a rope revolving in a groove they thought something alarming was going on, while as a matter of fact there was not. The revolution was, at the most, a very slow process, and was simply a gradual moving round of the rope, which was by no means so rapid as to induce any considerable wear. It was, to his mind, due to the spirality of the rope, and took place throughout the whole length. Some engineers had a great idea of revolving ropes, and in Lancashire there were a large number of ropes working that were continually revolving, but which, if this had proved in any way detrimental, would have been discarded. He was sure there was not that amount of harm in it which the author had indicated.

As to a rope bedding itself down in the groove, and assuming a sort of wedge shape, he would like to ask whether a rope assuming that shape would not get such a firm grip of the groove that the difficulty of getting it out would be much greater than if it maintained a cylindrical form. This point should be carefully considered, as it was the object of all engineers, in rope-driving, to avoid, as far as possible, any approach to a wedging action, because it was destructive, and a great source of loss of power. He would like to be assured that this action did not occur in the particular form Mr. Kenyon referred to.

With respect to electrical engineers, and the remarks of Mr. Crompton, he thought if the latter gentleman had had any

practical experience of rope-driving he would not have condemned it as he did. He might add that although many electrical engineers were highly trained theoretically, and thoroughly understood electricity, when the question of power transmission was brought before them their knowledge on the subject was so small that their opinions were very often based on absolute ignorance of the true conditions. It would, in the future, have to be a necessary portion of the training of an electrical engineer that he should be educated in the development and use of steam and the transmission of power. They would, perhaps, then see rope-driving more largely adopted for electric stations, and there would be an absence of the objections which were at present urged against it by electrical engineers.

Continuous driving was undoubtedly a fallacy. By taking a single rope over a number of pulleys instead of separate ropes they got a worse drive, and one which was nothing like so regular, and had not that equality of tension which had often been claimed for the continuous system.

The power which a rope would transmit depended upon such a large number of circumstances that it was impossible to lay down any hard and fast rule. It was a question which must be decided upon according to the circumstances of each case, and depended not only upon what the rope would stand and transmit, but also on the length of time which the rope was expected to last. If they intended to renew the ropes every two or three years, then the 93 HP through a $1\frac{3}{4}$in. rope was an example to follow; but if it was intended to renew them less frequently they would have to transmit a smaller power. He thought with Mr. Pickworth, that a gross working tension of 200lbs. per square inch was a good basis to start on, and was borne out by the most modern practice as being a safe working limit for main-driving ropes.

He could not understand why there should be such a superiority on the side of American cotton as compared with Egyptian. The microscopical structure of Egyptian induced them to believe that it would be the best for ropes. There were more fibres in the cross-section of each strand of yarn, the fibres themselves had a higher spinning quality, and were more even in diameter and length, and he could not help thinking that there was still something to be said for Egyptian cotton as a material for making ropes. The same considerations which, in his opinion, would make Egyptian the best material for ropes rendered all kinds of hemp a worse material than any class of cotton. The bending of a fibre of hemp upon itself a few times would lead to rupture much sooner than bending a fibre of cotton, and the constant bending and straining speedily reduced a hemp rope to powder.

This question of bending affected another point. The author had advocated pulleys 50 times the rope diameter, which, as Mr. Saxon pointed out, was, in many cases, quite impossible. There were very few cases where they could get the smallest pulley 50 times the rope diameter. Taking a 1½in. rope, which was a favourite size, the pulley would have to be 75in., which, in many instances, was not practicable. The question arose whether the use of the smaller ropes in Lancashire did not arise from the fact that the bending of a smaller rope repeatedly over a pulley was accompanied by less damage than the bending of a larger rope. In the latter case there were more strands to bend, the rope was much stiffer, and did not bend and straighten as easily as in the former case, and it was therefore a question whether the smaller rope was not the best rope for main-driving. As to three *v.* four-strand ropes, the author had stated his preference for the former, because it needed no core, which in the four-strand rope became pulverised and broken. Now he had brought with him a piece of four-strand rope, which had

worked for ten years night and day, and he would defy anyone to point out any trace of a pulverised centre in it. Even taking the three-strand rope, there must be in the centre a certain space, and when pressure was exerted to close up the fibres of the rope, this must also result in closing in the centre in some shape or form, and it did not appear to him to matter much whether they filled in the space with a flexible core of the same material or left the space to be filled up by means of the rope itself. Certainly he did not agree as to the absolute superiority of the three-strand rope over the four-strand form.

With regard to crane ropes, and the preference arrived at by Mr. Kennedy's friend for three-strands for the above purpose, and four or more strands for main drives, there again the question arose as to the circumstances under which the rope was working. In one case the rope was passed over a lot of small pulleys at sharp angles, and ran at a slow velocity, as compared with that of the main-driving rope, where they could run it over large-diameter pulleys. The rope was bent over a surface altogether different from the other, and three-stranded rope would bend more easily in the one case than the four or more strands, which, in their turn, would bend more easily over the larger diameter. The experience of the author's friend did not bear out the inference deduced by the author.

The stretch of ropes was a subject of great importance. A rope which stretched too much was, of course, a very bad one to have in connection with a main-drive, and he thought, looking at the make of rope submitted to them that night—whilst there were other makes which ensured that there should be no stretching—the method shown for getting equality of tension in the strands would tend to greatly diminish stretching.

He might conclude by saying that they wished to find out which was the best kind of rope, and the truth lay partially in one and partially in the other form. One acted very well in

one case and the other in another. The difficulty in dealing with such questions was to generalise, as so many circumstances entered into consideration that this was practically impossible.

Mr. F. W. Reed referred to the question of corded ropes, that is, where the strands were formed of separate cords twisted together as compared with stranded ropes. He had found the stranded rope the best. The corded rope, being made harder twisted than the stranded rope, offered a greater resistance to bending round the pulleys and got worn out sooner. The stranded ropes were more supple, and had in many cases from one and a half to double the length of life.

Mr. T. Settle said there were some cases where hemp ropes did well. He knew of one instance where the hemp rope was exposed to damp, and it acted very satisfactorily, giving better results than the cotton rope. The author might include Kirkaldy's tests in the revised paper, and also give his ideas as to what he had found from practice to be the best working load per square inch.

Mr. S. Cook said he had seen four-strand cotton ropes working in paper mills, and giving better results than manilla ropes.

It was, in his opinion, far better for ropes to revolve, because this caused the ropes to wear round, whereas if they did not rotate they wore to a V shape, and were much more difficult to re-splice than when worn round. He knew a good many people, both engineers and cotton-spinners, who were particularly anxious that the ropes should revolve.

He strongly advocated the four-strand ropes; they were rounder. It was a mistake to think the heart would break, and he had known four-strand ropes to run 20 years without this occurring. The author had stated that three-strand ropes were stronger than four-strand ropes, but he might mention that

strength was not the only thing to be considered in driving ropes. One of the main points was freedom from undue stretching.

From a large experience he had found Egyptian far better than American cotton, and most cotton spinners requested that the ropes should be made from Egyptian cotton.

Mr. T. WALTON referred to a case where the elasticity of rope driving was of great service in neutralising the jerking and irregular turning of an engine, and converting it into steady turning for machinery. The engines were a pair of horizontals, with heavy reciprocating parts, with, in his opinion, the cranks at wrong angles. The engines had been altered from spur driving to partial spur and partial rope driving. On account of a continual jerking of the engine and irregular turning the ropes were so punished, owing to the necessity of keeping them tight to prevent mounting the grooves, that they had frequently to be thrown off and replaced. The rope-maker was referred to, the owners ignoring the real cause of the trouble, which lay in the engine. Ultimately an alteration in the position of the cranks effectively remedied the matter.

He did not think that rope pulleys would always be heated when slipping occurred, unless there was a great amount of slip, as at high speed he thought the heat generated on the pulleys would be radiated and carried off by the air currents about the pulleys and ropes.

The PRESIDENT (Mr. J. Nasmith) proposed a vote of thanks to the author for his valuable and interesting contribution.

Mr. T. ASHBURY (Past President) seconded, remarking that he had recently visited a works in the West, where the engineer had adopted rope-driving, and made the grooves exactly to suit

the ropes. They were curved at the bottom, and the driving consequently proved a great failure. He would have liked to hear more about steady driving. He had been in a works whose founder claimed to be the inventor of rope-driving, and noticed that they adopted a continuous drive, with, however, unsatisfactory results.

Mr. KENYON briefly replied at the meeting, and subsequently communicated the following written reply :—

Mr. G. Saxon may be congratulated upon the thoroughly practical manner in which he has dealt with the question of rope driving. His reference to the tests upon three and four strand ropes has led to the incorporation of the sample tests, which may be verified by reference to Kirkaldy's book.

CORES IN FOUR-STRAND ROPES.

Evidence *ad libitum* might be produced in support of the statement that the cores of four-strand ropes break up from the strain exerted under ordinary driving conditions, resulting in over riding strands, frequent tightening and subsequent premature removal. By way of confirmation, the results of a few recently-investigated cases bearing upon this point might prove of interest to the discussion. In one instance, a four-strand rope was removed after five years running and frequent tightening. When opened, the core was discovered to be broken at short intervals. The strands had extended beyond these fragments, and closed in with the usual distortions. In another rope the core was completely pulverised, and crumbled to pieces when exposed. A core made up of three strands, and moderately hard twisted, was found to be in good condition, but the inner portion of the strands had so scrubbed against it from spiral extension as to fray the fibres all along the line of contact: this rope had worked four years. Yet another four-strand rope, removed after twelve months running, appeared to be in fair con-

dition throughout. The chief difficulty with this was considered to be in its rigidity, the stout core having stiffened it so much as to render it incapable of gaining a firm hold upon pulleys and grooves, with the result that it continually wandered out of its path.

Almost any rope may do moderately well where the conditions are all that could be desired, and it is quite possible that a core may go unpulverised, particularly in a two-inch length similar to that exhibited by the president, whose contention, that it did not much matter whether the centre space was filled up by the main body of the rope or by a flexible core, falls to the ground when the fact that the spiral extension and contraction, which plays so great a part in the elasticity of the rope, is held in check by a strand laid evenly through the centre; or, when the difficulty of keeping four strands in their respective positions is considered, particularly in bending round small diameters.

It is quite an easy matter to force the strands out of place by hand, notwithstanding the core. Not so with a three-strand rope, which, tripod like, will stand its ground and submit to almost any amount of bending and distortion without permanently disturbing the relationship of the strands to each other. Try the simple experiment of pressing coins of the same size together, first with four, then with three, and the difficulty mentioned will be all the better realised.

Throughout all his experience the writer cannot recall a single drive of four-strand ropes, either made by his or any other firm, where these distortions have not been present and very apparent to the practical eye.

CORDED *v.* PLAIN LAID ROPES.

The writer's firm always makes small sizes of ropes, from 1in. diameter downwards, plain laid, and only cord the larger sizes on account of being more convenient for splicing. He therefore

corroborates all Mr. Reed has said upon this point, which is also very clearly demonstrated in rim and scroll bands.

COTTON *v.* MANILLA.

With respect to the instance cited where manilla ropes have lasted six years, it would appear that these are running under the most favourable conditions. Assuming the ropes to be 1¾in. diameter, the smallest pulley is nearly 55 times that. Let the aforesaid manager try really good cotton ropes for once, and, what with their flexibility, the higher rate of power transmitted, and greater general efficiency, it is almost certain manilla would also take a second place with him.

Further, cotton ropes are now rapidly supplanting manilla, where only a few years ago they could find no place whatever, by reason of those districts being so largely engaged upon the manufacture of manilla goods generally.

Cotton ropes have certainly proved more effectual for withstanding the effects of damp than any other class. It is well known that evaporation readily takes place through its fibres, while hemp retains moisture, and mildews in consequence. Hence the reason why they are so extensively used on canals, and have proved far more durable for ships' cables, for mining, and outside work generally.

The writer's experience is certainly quite opposite to the instance quoted by Mr. Settle, and he can call to mind several cases of paper mills where cotton ropes have been completely submerged but have run for years after. They are also far better for countries which are subjected to the extremes of atmospheric changes.

AMERICAN *v.* EGYPTIAN COTTON ROPES.

The writer quite agrees with the President that the microscopical structure of Egyptian is totally different to American cotton, in that the fibres are much finer and have a higher

spinning quality, &c., as suggested in the paper, all of which qualities were scientifically investigated years ago by his firm; and he will even go so far as to state that more weight may be compressed into the same bulk, therefore making a more solid rope. But, surprising as it may appear, the not unreasonable theory that it should do better for this purpose entirely collapses, like not a few other theories, when submitted to practical test. The market value of the Egyptian yarn used in the experiment mentioned was estimated at fully 40 % greater than the American, on account of its having been spun down from a very fine mixing of cotton. This should serve as a hint to those who will insist upon having the questionable luxury of Egyptian at a low price.

Not very long ago the same firm was called upon to replace, with American cotton, ropes made from silk waste, which had only run for a short period. The writer is content to leave any deductions which may be drawn from this to the imagination of his friends.

ROPES REVOLVING IN THE GROOVES.

No theory has yet been advanced which quite hits the mark as to the rotation of a rope on its axis. This effect has been attributed to the spirality of the rope, and to the twisting and untwisting when passing from tight to slack side. The plunging of the pulley causing a slight deviation from the straight driving line has been held responsible in one case, in another, inequality of twist in the rope itself, and so on. But if any of the above reasons may be taken as valid, how comes it that, say, out of a drive of 12 or 20 ropes, which shall be cut off one long length and equal in twist, number of ends, weight and strength throughout, there may be one rope revolving in its groove and all the rest fixed. A slight difference in the gauge of the groove was suggested as the cause in one case of this kind, and the substitution of a rope a shade thicker than the original, put on tight, effectually stopped the evil. In the majority of cases, however,

as mentioned in the paper, fixing the ropes pretty tight to begin with and running for a short time without load will often produce the desired effect.

The use of grooves with curved sides cannot be too strongly deprecated, as being a fruitful source of encouragement to rotation. The writer must express his surprise that Mr. Cook should know so many engineers and cotton spinners who are opposed to this view of the question. The reverse has been his experience all along, and he is frequently in consultation with eminent engineers (who have made a special study of rope driving), with a view to ascertaining the cause of and coping with the difficulty.

In estimating the damage from this cause every precaution was taken so as to arrive at a fair average of the numerous reports submitted, with a view to remove any lingering doubt which might remain. These were again submitted to an engineer (to whom the writer is indebted for much valuable information) in charge of three large engines of different types. This engineer has kept a correct account of every rope, giving full particulars as to the time of fixing, attention required, renewals, &c., during a period of 18 years. By him this assessment, viz., that the act of revolving in the grooves reduces the durability of the rope by one-third, was considered, if anything, an error in the direction of longevity, giving as his reason that whilst many of the fixed ropes had run without tightening for 18 years, and were still in good condition, the revolving ones required frequent attention, some having been renewed after only running half that time.

There remains, therefore, not a shadow of doubt on the writer's mind that this rotation very seriously detracts from the life of ropes, notwithstanding the slight importance the President attaches to this branch of the subject.

WEDGING ACTION.

The statement under the head of "Wedging action, and the high rate of power transmitted by fixed ropes" is the writer's only answer to the suggestion that when ropes become cuneiform they conduce to destructive wedging action and consequent loss of power.

It may be here stated that in the experiment referred to it was found impossible to hammer a short piece of good cotton rope so well into the groove that it would not fall out from its own weight when the pulley was turned over. Again, this offers no impediment whatever to the re-splicing of ropes.

EFFECTIVE WORKING STRESS.

With respect to the rule laid down by Mr. Pickworth, that an effective stress of 200lbs. or 160 times the square of the normal diameter only may be relied upon, surely this may be considered a very low estimate for $\frac{3}{8}$in. diameter rope, whose breaking strain is 1,667lbs., or almost ten times the effective stress given. This superior strength may to some extent account for the abnormally high rate of power transmitted by one rope under the exceptional circumstances mentioned on page 251.

HEAT FROM SLIPPING.

Under this head the writer can only say that he has never yet investigated a case of slipping where heat has not been set up upon pulley rims; and this applies also to high speeds.

CRANE ROPES.

The writer most willingly accepts the suggestion respecting crane ropes having to pass over a lot of small pulleys at sharp angles, and run at slow velocity as compared with main driving ropes, where they could run over large diameter pulleys, as an argument in all points favourable to his contention throughout, viz., if three-strand ropes will do better than four under most unfavourable conditions, it is only a matter of degree not of

general principle, and he, at least, would prefer to have such ropes for drives where every detail has been worked out with a view to producing the best possible results. Give him men of good physique for either forced marches or parades.

GROOVES.

The chief difficulties arising from badly-shaped grooves is that the ropes never thoroughly settle to their work, and are a constant source of anxiety from the frequency with which they roll out and over each other.

Where both pulleys are not grooved out to the same template, it is often necessary to gauge the rope to the largest size, which invariably means running over the edges instead of into the smaller grooves, much to the detriment of the ropes, besides causing loss of power from want of grip.

The style of setting out a groove is simply intended to illustrate an easy method of fixing the working position of any diameter of rope at 40 degrees in order to lift it well above the bottom, and, although this angle is found to work well, a difference of a few degrees is not a very serious matter. If, however, grooves are made too obtuse, the drive suffers from loss of frictional power. Nor is it necessary that the groove should terminate with a curve, either at its junction with the flange or at the bottom. Flangeless grooves, as Mr. Alfred Saxon mentions, may be advantageously adopted, particularly where it may be found necessary to afterwards increase the power, which may be accomplished by substituting thicker ropes, whereas flanges prove a barrier to such extension.

DRIVING WITH ROPES OUT OF PARALLEL.

Where shafts are only slightly out of parallel they may be driven with ropes, without the introduction of guide pulleys, simply by making the grooves without flanges, and, say, half as wide again at the mouth as the rope itself. Rectangular driving

may be accomplished by the aid of two carriers, grooved with the number of ropes required, and so fixed as to guide them into their rightful position. (See Plate 15.) In this case the shafts are shown one higher than the other. This system may be applied to almost any other angle, and with the shafts on the same level, but the circumstances vary so much that it would be almost impossible to design an arrangement applicable to every case. The writer would, however, be pleased to give his opinion upon any special difficulty which may be submitted to him. In cases where shafts are out of parallel, and one over the other, crossed ropes have been successfully applied. The grooves, being double the pitch or alternately used, combine with the angle to prevent the ropes rubbing each other in passing. It should always be understood that no system of angular driving is so effective as driving along the straight line.

CONTINUOUS DRIVING.

As to continuous driving, the writer has inspected many examples in America and elsewhere; but the best of them only serve to establish all the firmer his conviction that driving with separate ropes for each set of grooves stands far ahead for safe, effective, and economical working.

ROPE DRIVING FOR ELECTRIC INSTALLATIONS.

The writer acknowledges his indebtedness to Mr. Bennett for his admirable arguments in favour of rope driving for electric lighting stations, which are a valuable contribution to this discussion. Many reasons might be given why ropes do so much better than direct coupling. The dynamo is placed well out of reach of steam, oil, and other damage consequent upon its too close proximity to the engine. Again, in cases where an alternator is running in parallel with another plant, the resilience of the ropes themselves regulate any difference of pace between

them, without transforming an over-charged dynamo into a motor *pro tem.*

While it is true that a rope-driven plant cannot be contracted within the limits of engine and dynamo combined, it may be so arranged as to cover very little more extra space by elevating the dynamo. Taking this into consideration, it may be safely assumed that the superior effectiveness of this system, coupled with the economy mentioned by Mr. Bennett, would, even in crowded districts, more than compensate for the costs chargeable upon the little extra land required.

No doubt, as Mr. Pickworth suggests, the statement referring to electrical engineers driving on to pulleys out of all proportion with the size of the rope may to some extent be the outcome of their endeavour to secure the best results from small high-speed dynamos, which are generally acknowledged to be more efficient than the larger sizes, running at a slower rate. But whilst a little latitude may be allowed upon the 30 diameters in thin ropes, the difficulty can be overcome by adopting larger fly wheels, which have the advantage of bringing up the driven pulley to the regulation size, by increasing the rope speed.

METHOD OF HOLDING ROPES WHILE TESTING.

A very simple method is sometimes adopted for holding ropes while testing. Two couplings are prepared, with conical or bell-shaped holes, the narrow portion being made exactly to the diameter of the rope, through which the ends are passed and opened out so as to loosely fill the cone. Hot resin is then poured amongst the fibres, which when cool prevents the rope dragging out during extension. Kirkaldy's method remains, of course, unpublished.

PATENT FAST AND LOOSE PULLEYS.

Although applicable to rotary motion generally, the patent fast and loose pulleys are specially designed for textile

machinery. In cotton mills, of course, there would be no difficulty whatever in the matter of splicing, as any minder could do the work, and in other large concerns it would pay to engage a splicer who could devote a part of his time to this purpose.

This method has certainly passed its tentative stage, and has proved an unqualified success. Lighter shafting, more definite transmission of power, considerable saving in cost, and immunity from accident so often caused by the breaking of large belts are amongst the advantages claimed. They also supply a long-felt want for hot countries, where belts so soon dry up and become useless.

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15 Plates follow illustrating this Paper.

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REMINISCENCES OF THE VISIT OF THE IRON AND STEEL INSTITUTE TO SPAIN.

READ SATURDAY, 28TH NOVEMBER, 1896,

BY

MR. HENRY WEBB.

Mr. HENRY WEBB, of Bury, delivered an address to the members on the above date, his subject being, "Reminiscences of the Visit of the Iron and Steel Institute to Spain."

The PRESIDENT, Mr. Joseph Nasmith, occupied the chair.

The address was illustrated by a number of lantern slides, most of which were taken on the excursion by members of the Institute, and which had been specially prepared by Mr. Webb for this meeting.

In the course of his address Mr. Webb said:—Doubtless you have wondered why the Iron and Steel Institute decided to visit Spain. It is the custom to meet twice each year, in the spring in London for the reading and discussion of papers, and in the autumn in the provinces, when in addition to the reading of papers excursions are arranged to places of interest. In this way they have visited the chief towns of England, Scotland, and Ireland; have visited Belgium twice, France twice, Germany once, and America once; and it was thought that, inasmuch as vast quantities of Spanish ore are used in England, and the President of the Iron and Steel Institute, Sir David Dale, is also chairman of the company owning the largest mines in Spain, and the next President is the largest user of ores, a trip to see the mines, which are situated in a lovely district, would be

appreciated. The difficulty was the hotel accommodation. Spanish hotels have not the highest reputation, and they could not arrange for the numbers wishful to go, therefore it was decided to charter a steamship, and let it serve as a floating hotel.

The vessel selected was the "Ormuz," one of the finest vessels in the Orient Line of Royal Mail Steamers, designed and built by the Fairfield Shipbuilding and Engineering Company, Limited, Glasgow. This ship is very compact, well arranged, very clean, and as comfortable a ship as anyone need wish to travel in. The steerage berths were all removed, and the whole ship was placed at the service of the 250 members, the sum of £7,000 being guaranteed. There is nothing but praise to give to everyone, from the captain to the ordinary seaman, and the *cuisine* was excellent. Life aboard passed very pleasantly, especially to twelve good men and true from the Manchester district. They sat together at table, and generally were together on the various excursions, and this greatly enhanced the pleasure of the trip. We left London at noon on Saturday, Tilbury Dock one hour later, and reached Portugalete on Monday morning about eleven o'clock, and anchored about three-quarters of a mile from the shore in 42 feet of water. The sky was somewhat cloudy, windy, and threatening rain, but the first impressions of the country were pleasant—hills coming down to the sea shore, looking green and fresh; and the white houses, with red-tiled roofs, nestling in the valleys, looked picturesque. We were soon surrounded by boats—long, narrow, heavy, rough boats, with 14 oars each, and steered with another oar, filled with boys, girls, and men, come out to see the big ship. The men and boys were sinewy and brown-looking, and as they were out for pleasure and not work they pulled well and seemed excited and amused, and worked very hard indeed.

After an early lunch we got on the tender for a sail on the river Nervion, about ten miles up which Bilbao is situated. At the mouth of the river is Portugalete, a fashionable seaside resort with fine sea views. It is a town of steep streets and hills, and has a picturesque Gothic church. The beach is good for bathing, and crowded with bathing vans. As our tender approached the pier we noticed the streets were decorated and filled with people; every house, too, was decorated, and every window full of people; rockets were fired in every direction, and dynamite bombs were exploded on the hills, the loud reports from which echoed from side to side. There was much waving of handkerchiefs and attempts at cheering, but the Spaniards cannot cheer like Englishmen. The most striking object is a graceful iron bridge which spans the mouth of the river, and the only one of its kind, designed by a Spanish architect, Don Alberto de Palacio. This bridge connects the town of Portugalete with the village of Las Arenas.

The problem to be solved was to provide a means of communication for passengers, cattle, and vehicles, without interfering with the passage of ships, and at a moderate cost. This is effected by suspending a spacious trolley from an overhead superstructure, supported by lofty towers on either side of the river, the trolley being hauled to and fro by wire ropes, driven by a steam engine fixed in one of the towers. In fact, in principle it is the span of an Otto ropeway on a large scale, adapted to public traffic. The clear span between the towers is 581ft.; the height of the roller path from which the trolley is suspended to high water spring tides is 147ft., the height of the towers is 203ft. The total weight of the iron structure is 600 tons, while the cables weigh 110 tons. The cost was £20,000; the weight of the trolley is 14 tons when empty, but included in this weight is that of the suspending cables and roller gear. It

is constructed to carry 30 tons of live load. The engine is 25 HP, though from 7 to 9 HP only is required to drive the trolley on ordinary occasions. In high winds, however, the entire power is sometimes needed.

We steamed slowly under this bridge, the roadways being thronged with people. In the river on both sides were many large steamers, mostly from England, come for ore. There are many shipping slaithes, which seemed to be of very solid construction and well fitted for handling large quantities of ore expeditiously. The trucks come direct from the mountains and tip their contents into the holds of the vessels. We went about four miles up the river, noting the facilities for loading and unloading. The iron and steel, and other works are on both sides. On returning we landed at the Axpe Docks to see the quarries and contractors' yard and workshops for making the concrete blocks, 60 tons each, used in the construction of the breakwater and counter mole which are being made outside the mouth of the river, to cost £1,250,000, and to be paid for from funds obtained by levying discharging duties on coal and merchandise and export dues on iron ore. The cranes for handling the blocks and loading them into barges, also the titans, are worked by electricity.

We returned by tender to Portugalete, where we were again greeted with a fusilade of rockets; several balloons were sent up, shaped like men, animals, and fishes; we witnessed a boat race; and then walked along the *boulevard* to the bathing pavilion, where afternoon tea was served. At six o'clock we returned to the "Ormuz," but it was very tossy and difficult to get on board owing to the swell on the water. After a hurried dinner and dressing the majority returned at 7-30 to Portugalete, thence seven and a half miles by rail to Bilbao, for a reception fête and concert in the Arriaga Theatre, arriving back at the ship at one a.m. next day! Rather hard work—up at

5-30 a.m. and to bed at 1-30 next day! For those who remained on board there was a dance on the promenade deck. The effect of the recent improvements to the port of Bilbao are that at high water, in all ordinary spring tides, steamers drawing 22ft., and at neap tides 18ft., can pass out freely, and this has reduced freights to England from 10s. 6d. to 4s. The river is illuminated at night by electric light between Portugalete and E Desierto for two hours before and two hours after high water, when ships are allowed to enter and leave the port. The largest vessel that has ever sailed up the river drew 22ft. 10in. of water aft, and carried 5,380 tons.

The next day opened beautifully fine, with a clear blue sky, slight breeze, and promise of a blazing sun. We were early on the tender for Portugalete, and from there took train to Bilbao. This railway lies on the left bank of the river Nervion, and has the normal gauge. It was opened in 1888 with a single line. A double line from Luchana to Bilbao was opened in 1892. The total length is seven and a half miles, and there are seven stations. We were pleased to see that the engine that was to take us was made by Nasmyth, Wilson, & Co., of Patricroft, and looked in good order, clean, and well-groomed. The station at Bilbao is in the most densely-populated part of the town, and is connected with the Northern Railway, and I thought looked somewhat neglected and dirty. The streets were crowded and busy, and there were many bullock waggons, or long, clumsy carts, with solid wood wheels 1½in. to 8in. wide. There were no cart horses, and the cab horses are like skeletons—bony, dirty, ill-used animals. The mules looked better. The people also looked poor, badly and lightly dressed, with hemp shoes with canvas tops. The buildings were good and shops very fair and numerous.

The market was an interesting and curious sight, there being hundreds of women there, chattering, each with her

basket, in which she had brought her produce to sell, and some with small stalls. There were tomatoes, pumpkins, melons, peaches, apples, pears, grapes, strawberries, chilies, onions, garlic, fowls, eggs, cheese, potatoes, butter, green vegetables, all kinds. We had a feast of strawberries for four, for 8d. Walking on, we looked into three churches, mostly gloomy, with elaborate and gorgeous altars, and several worshippers. Then on to the Provincial College, where in the Salon de Actos we were to be received by the Mayor, but he was absent from a rather remarkable cause. It seems that on a recent occasion a Socialist and a Republican Councillor had a quarrel, which resulted in the Republican throwing an inkstand at the other, at a meeting of the Council. This led to a demand on the part of the Mayor for the punishment of the offender. The Government took the matter up, and it is alleged that on a promise being made by the Republican that he would not only not offend again, but would in future support the Royalist party, he was set at liberty and returned to the Council. This, however, was not enough for the Mayor, who had threatened to resign unless the offender was punished, and who now formally handed in his resignation. At the time of the visit of the Institute the resignation had not been accepted, but the Mayor nevertheless had made up his mind that the situation was such as to prevent him from representing the City as its Mayor, and, as the Council had appointed no one else to fill his place, the City was practically without a Mayor. In these circumstances, the senior Alderman attended the meeting on behalf of the municipality, although it was known that the Mayor was actually present in the body of the hall. After the usual complimentary speeches the formal business of the meeting was proceeded with. The first paper read was one by Don Pablo de Alzolo on "The Spanish Iron Industry." By the time this was concluded, your humble servant and some of

his friends had had enough of the scientific part of the proceedings, and preferred the open air to the stuffy room in which the meetings were held, so we strolled through the town, looking at shops, churches, etc., until we found the restaurant where lunch was to be served, and which I did not appreciate, as everything was so strongly flavoured with garlic.

After lunch we took the electric tram—"trolly system"—to the Euskalduna, or covered court where sports are held. This is 72 yards long, and will hold 3,000 persons. Here we saw the game of polata; dances by Spatadanzaris; quadrilles by traditional giants and dwarfs; and glees by the choral society of Bilbao. We arrived at the ship at six o'clock; left at 8·15 for conversazione in the Town Hall at Bilbao; and returned at 12-30.

The next day (September 2nd) opened with a mist but gave promise of a hot day—a promise which was fully realised. It was amusing to see men standing in a row waiting for a bath. After breakfast, at 8-30 we left for Bilbao, walked across the city to the Central Railway to visit Guernica, an ancient town founded by the Lord of Biscay, Don Tello, in 1366, 16 miles from Bilbao. It was a lovely ride, under a cloudless sky, with brilliant sunshine, through delicious valleys, well cultivated, with clear streams, maize fields in full fruit in abundance, vineyards, orchards, mountains on all sides of fantastic shapes, rising from 2,000ft. to 4,000ft. high, enchanting vignettes, and best of all a delicious air. You seemed to take a draught of renewed health at every breath. At a junction we were shunted on to a single line, and three engines were put to take the train to Guernica, the point of greatest historical interest in the Basque country. At the station we were met by a brass band, and forming in line we marched to the old Parliament House. At the front of this is the old oak tree, under which the ancient Biscayans used to discuss public matters and administer justice,

and at the foot of which all Spanish sovereigns knelt and swore to uphold the liberties of the Basques. Close to the tree, upon a stone platform, stands a small stone throne with twenty-two Corinthian columns 10ft. high, with cornice and Greek frontispiece. In face of this there are two small platforms. We viewed the Assembly Hall, where an interesting collection of the portraits of the Lords of Biscay have been placed, and a curious old painting representing King Ferdinand, the Catholic, swearing to maintain the liberties of the Basques. There is a most interesting library, and the archives are filled with rare old manuscripts and prints. Assembling around the oak, speeches of congratulation, etc., were made, but I gathered that the Biscayans were still resenting their absorption into the kingdom of Spain, as up to 1845 they had made their own laws and levied their own taxes. The choral society sang the Biscayan National Anthem.

It was a quaint scene—this large party in the open air, with heads uncovered, under a blue sky, and a brilliant sun; on one side the lofty mountain, on another a large convent with the nuns peeping through the iron-bound windows; and on a third side a lovely valley. We visited the grand old church; walked through the village, past their Town Hall; saw oxen ploughing in the fields, bullock waggons creeping slowly up the lanes, the village shop with leather bottles and wine in skins of animals; the whole scene, once seen ever remembered.

The history of Guernica and its House of Parliament, and its traditions, are well worth reading. The laws of the place will also repay study. Let me briefly give you three or four. (1) The real estate of delinquents cannot be confiscated for any fault, great or small. (2) Biscayans cannot be imprisoned for debt, unless this was originated by fraud, nor can their property be seized; the Biscayan's house is an inviolable refuge, where no bailiff can enter nor approach nearer than four fathoms.

Should he enter he may be resisted without penalty. (3) Whoever should lift his hand in wrath against his father or mother, or person who bestowed upon him property, loses his property for his ingratitude. (4) No one shall be allowed to gamble a larger sum than two reals, or 4d., and even this shall not be in a tavern. (5) Monopolies are prohibited, etc. We left by train to go a few miles to the Isla de Chachasiamendi, where a large new hotel had been built on a small hill. From the west side, between two hills, there is a view of the Atlantic Ocean as blue as blue can be; on the east as lovely a valley as you could wish to see. On a third side are other hills, on the south side of which are some good residences—one owned by the Empress Eugène. After a good lunch we had glees, etc., by the Choral Society, and some dancing by old peasants for coppers. We then rambled in the wood, and in a place cleared like a ring the peasants danced. We arrived at the ship at nine p.m., well tired, but had spent a most enjoyable, never-to-be-forgotten day.

The whole of the next day (September 3rd) was to be spent in a visit to the mines, and as we left the ship at 7-30 it was smart work to have your bath and breakfast before that time. We sailed right to the Orconera Co.'s wharf at Luchana, where three trains were drawn up ready for the journey to the mines. There were twenty-six waggons covered with red cloth, and seats for 466 persons. The engines were covered with flowers and greenery, and looked very gay. The coaches and the rails were made by English firms. Four classes of ore are known locally in the district. They are—Vena, red grain, which is soft purple and often powdery; Campaniel, red grain, compact and crystalline; Rubio, brown grain, hydrated, ferric oxide, silicious; and Carbonate, spathic ore, grey, granulated, and silicious, creamy white, laminated, and crystalline. Vena is generally the purest of the Biscayan ores, and was formerly the

only one used in the Catalan. Campaniel was first worked when the discovery of the Bessemer process gave a great impetus to the mining industry. Rubio is much mixed with clay and silicious matter. Carbonate, or spathic ore, is sometimes in small quantities enveloped in lumps of campaniel or rubio, but is generally found below these. Mining concessions in Spain are granted by the State through the civil governor of the province in which it is situated, the conditions being that there be free space and no prior claim. They are granted in perpetuity, subject to an annual payment to the State of a surface tax. There is no obligation to work the mine, and the title, once granted definitely, cannot be cancelled except through non-payment of the tax.

The taxes paid to the Government and local authorities are:—Surface tax, 2s. 8½d. per hectare (11,960 square yards); a tax of two per cent. on the value of the ore at the quarry mouth; and a port tax of 6d. per ton shipped. The quarries are worked open cast with one or two exceptions. The general practice of the district is to let the raising and loading to a contractor at a rate per ton of clean ore, delivered to the stock heaps alongside the various railways. In the open cast work the rock boring continues to be done by hand. Jumpers are used exclusively, even for small holes bored to split up the masses of ore brought down by the larger blasts. The holes are known as one-handed, two-handed, or three-handed, according to the number of men employed. In breaking down the ore after blasting, and in classifying it, the hammer, spade, hoe, rake, and baskets are used. The waste of baskets is enormous, but the necessity of selecting the ore and separating it from the rubbish in the act of loading the rake and basket seem to suit the purpose fairly well. The hours worked are, in January and February and November and December from half-past six to half-past five, with a rest of two hours; in March, April, September, and

October, six o'clock to six, with a rest of two hours; and in May, June, July, and August, from six to seven or five to six, with a rest of two hours.

Feast days are numerous, and what with these and bad weather the number of effective working days in the year may be taken as 285. The wages paid per day are according to the following scale:—Foremen, 8s. 6d.; men charging and firing shots, 2s. 6d.; drillers, 2s. 2d.; labourers, 1s. 10d. to 2s.; labourers at calcining kilns, 2s. to 2s. 2½d.; boys, 1s. 4d.; horse-drivers, 2s.; masons and bricklayers, 2s. 10d.; engine-drivers, 2s. 2d. to 4s.; firemen, 1s. 10d. to 2s.; brakesmen, 1s. 11d. to 2s. 0½d.; train-guards, 2s. 4½d. to 2s. 8d.; blacksmiths, 2s. 2d. to 4s. 4½d.; strikers, 2s. to 2s. 2d.; fitters, 2s. 6d. to 4s.; and carpenters, 2s. 6d. to 8s. 6d. The sanitary condition of the mining districts; the lodging, clothing, nutrition, and hygienic surroundings, judged by modern standards, fall far short of what they should be; yet, compared with other provinces in Spain, the lot of the people here is enviable. Consequently, with this, and attracted by the high wages paid, there is a constant influx of outside labour and the supply far exceeds the work available, except for the two harvest months. Labour troubles, though rare, are not unknown, thanks chiefly to Socialist agitators, who seek to sow discord, and thus alienate the sympathies of those who would gladly co-operate in efforts to improve the position and comfort of the workmen. The methods of mechanical haulage are four—Railways, Inclined Planes, Endless Chains, and Wire Ropeways.

The Orconera Iron Ore Company have a double main line which runs up the valley that forms, roughly speaking, the centre of the Orconera Company's property. It extends to a back shunt or V station, whence the branches to the various levels strike off at suitable gradients in fan-like forms. The ruling gradient is 1 in 30, but there are short lengths 1 in 25,

all falling in the direction of the mineral load. There are in daily service on these branches four locomotives of 24 tons each, three ditto 14 tons each, and two ditto 13 tons each; 284 mineral trucks, from 4 to 4½ tons each; 175 iron and steel rubbish waggons, containing 2½ cubic metres each. A mineral train is about 70 tons nett of ore. The company's rolling stock is:—Main line locomotives, 15; shunting, 8; main line 7½ tons iron and wood waggons, 570; ballast waggons, 30; goods, 17; passenger coaches, 5; inclined plane waggons, 300; and mining waggons, 560. There are four mining villages in the hills, which are from 1,200ft. to 1,500ft. above the sea, and as there is no cart road there is a daily service of goods, coal, and materials for their supply. At a point on the railway called Orconera Station, 5½ miles from the port, there is an inclined plane used for haulage, the length of which is 1,200 yards, of which 340 yards are upon a reverse curve. The average gradient is 1 in 5·8, the maximum being 1 in 4·75, and the total fall from brows to the foot is 612ft. The drums are 15in. diameter, 8ft. 8in. wide on the rope head, and are controlled by friction brakes. The cables are of best plough steel, are 4½in. in circumference, tested to 75 tons per square inch, and the average life of a pair of cables is 2½ years, or 1,455,161 tons ore.

The Société Franco Belge des Mines de Somorrostro, having several detached mines, and the nature of the ground being irregular, with considerable undulation, have adopted the Endless Chain because of (1) its adaptability to the undulations of the ground; (2) the readiness with which the branch lines can be extended in different directions; (3) the small cost of working; and (4) the large limit of variation permissible in daily working, by altering the speed of the chain and the space between the tubs. The total length is two miles. The difference of level is 802ft. and the maximum gradient is 29·5%.

The Somorrostro Iron Ore Company have three complete and independent groups of Ropeways, each composed of three separate lines, and each is started by a stationary engine requiring from six to eight HP. The lines are supported on wooden trestles, some of them 170ft. high. The buckets are of iron and carry 3½cwt. The cables are of steel, 1in. diameter, tensile strain 40 tons, and average life 125,000 tons, lasting from eighteen to twenty-four months. The largest quantity brought down by a single line in one year is 142,000 tons; in one day 914 tons.

The total quantity of ore shipped from the Bilbao river in 1895 was 4,124,000 tons, of which 3,122,000 tons came to British ports. The exports of the present year bid fair to reach 5,000,000 tons and will be the highest on record. There are fears that the supplies from this district will be exhausted in from eighteen to twenty years. These mines we saw on as perfect a day as you can possibly imagine, riding first in open waggons on the well-laid lines to the Orconera Railway Station. Then we were whizzed up the incline in four minutes, rambled round one of the largest mines, were told they had just obtained a concession of the hill-top close to, but had one million tons of clay, etc., to shift before they could get any ore. Preparations were being made for a blast on a large scale; we witnessed a drilling contest, returning to the ship at five o'clock, after which a reception was held on the promenade deck, which was decorated with banners and illuminated with the electric light. There was also a concert in the saloon, which lasted till 11-30. Thus ended our visit to Bilbao.

Mr. S. Dixon said at many of the engineering works he had visited in Spain, although they were making great developments, and were in a position to deal with a large amount of heavy work, with respect to machine tools they were only starting where English firms were leaving off, and were some-

times ten to fifteen years behind. At one works, where they were making the finest steel castings he had ever seen, the manager expressed the opinion that very often the work could be got out from England in less time than they themselves could finish it. This was, he thought, due to the poor machine tools, etc., they used, which were, in many cases, bought simply on the question of price, but which were utterly unable to cope with the work they had to do. Speaking generally, he might say that they had not learned very much from the visit, from an engineering point of view, bnt it was always interesting to see what other countries were doing.

Mr. PERCY observed that undoubtedly the better class Spanish ores were getting exhausted, and it would be a national loss to this country when this occurred.

The PRESIDENT proposed, Mr. ASHBURY seconded, and Mr. GREGORY supported a vote of thanks to Mr. Webb and the other gentlemen who had spoken, and Mr. WEBB having responded, the proceedings closed.

41ST Annual Report

OF THE COUNCIL.

1896.

MANCHESTER
HERALD & WALKER, TYP., POOL FOLD CHAMBERS, OFF CHAPEL WALKS.
1897.

OFFICERS.

1897.

President:

MR. JOS. NASMITH.

Past-President:

SIR E. LEADER WILLIAMS, M.INST.C.E.

Treasurer:

MR. JAMES WALTHEW.

Trustees:

MR. G. CARTER,
,, T. ASHBURY, A.M.INST.C.E.
MR. JOHN WEST, M.I.C.E.
,, SAML. DIXON,

ALDERMAN SIR W. H. BAILEY, J.P.

Council:

MR. J. BOLAS,
,, F. W. REED,
,, F. SLADE,
MR. A. SAXON,
,, W. SPENCER,
,, W. SMITH.

Librarian:

MR. JOHN GIBBON,
21, Wellington Terrace, Reddish.

Secretary:

MR. FRANK HAZELTON,
63, Barrett Street, Old Trafford, Manchester.

Annual Report of Council,

1896.

The Council have pleasure in presenting the 41st Annual Report of Proceedings.

To the membership roll during the year have been added—

2 Life Honorary Members.
9 Honorary Annual Members.
15 Ordinary Members.

Total 26

and after taking into account the loss by death, resignation, and erasure, the total number of names of all classes on the roll amounts to 381, as against 368 in the previous year, namely :—

28 Honorary Life Members.
128 Honorary Annual Members.
225 Ordinary Members.

381

Upon reference to the Financial Statement, as certified by the auditors (see page 321), it will be seen that the balance standing to the credit of the Association, after payment of all accounts due up to the 31st December, amounts to £3,849 18s. 3d., as against £3,645. 15s. 1d. at the close of the preceding year, thus showing a surplus of £204. 3s. 2d. on the year's working.

They are pleased to report that the payment to the super-annuant members has been at the rate of 8/6 per week, and

that during the coming year this allowance will be increased to 10/- per week.

It is with profound regret the Council have to record that during the year death has removed the following members, brief memoirs of whom are appended on pages 817 to 820. In accordance with resolutions, letters of condolence and sympathy have been forwarded to the families of the deceased members :—

Cannell, T. S. - - -	Manchester.
Galloway, John - - -	Do.
Peacock, W. H. - - -	Do.

The following gentlemen have resigned their membership during the past year :—

Attock, F. - - -	Manchester.
Guthrie, H. - - -	Do.
Knapman, W. B. - -	Do.
Wood, J. W. - - -	Hyde.

The following gentlemen have ceased to be Members during the past year :—

Farmer, J. S. - - -	Manchester.
Hodgson, H. E. - - -	Cleckheaton.
Kay, J. - - - -	Bury.
Lowe, E. J. - - -	Manchester.
Storey, H. - - -	Do.
Summers, J. - - -	Stalybridge.

The following gentlemen have been added to the Membership Roll during the past year :—

LIFE HONORARY MEMBERS.

Boocock, J. - - -	Oldham.
Richards, E. Windsor -	Bradford.

HONORARY MEMBERS.

Bamforth, Sam - - -	Glossop.
Foster, H. - - - -	Manchester.
Holland, R. S. - - -	Dinting.
Hughes, G. - - -	Manchester.
Ingham, W. - - -	Do.
Massey, H. F. - - -	Do.
Do. L. F. - - -	Do.
Robinson, Mark H. - -	London.
Spenle, J. - - -	Salford.

ORDINARY MEMBERS.

Atherton, T. - - -	Warrington.
Bayliss, W. - - -	Manchester.
Buck, G. F. - - -	Do.
Bennett, J. A. - - -	Horwich.
Beard, J. - - - -	Manchester.
Dobson, J. T. - - -	Do.
Gass, E. M. - - -	Horwich.
Heap, W. - - -	Manchester.
Kilburn, R. - - -	Do.
Lees, S. - - - -	Oldham.
Massey, E. - - -	Warrington.
Matthews, J. - - -	Manchester.
Poole, J. - - - -	Radcliffe.
Parry, J. - - - -	Manchester.
Shaw, H. - - - -	Do.

Similar to last year, 17 General Meetings of the Association have been held, 18 of which having been for literary or business purposes, two to inspections, and the remainder to social gatherings. The visits of inspection were as follows :—

June 25.—Crewe, for inspection of the Locomotive Works of the L. & N. W. Railway Company. Attendance 90. (See page 316.)

Oct. 10.—Inspection of the Electrical and Hydraulic Installations of the Manchester Ship Canal at Old Trafford; also of the Lairages at the New Foreign Cattle Wharf, Mode Wheel. Attendance 120. (See pages 160 to 171.)

Papers Read and Discussions held during the Year.

Jan. 11.—**Inaugural Address** by the President, Mr. Joseph Nasmith, on "**The Inventive Epoch in the Cotton Trade.**"

„ 25.—On "**The Transmission and Application of Hydraulic Power to Machine Tools,**" by the late Mr. R. Tweddell, M.Inst.C.E.

Feb. 22.—On "**Welded Steel Mains and Joints,**" by Mr. J. G. Stewart, Glasgow.

Mar. 14.—On "**Electric Driving,**" by Mr. Daniel Adamson, Hyde.

„ 28.—On "**The Development of the Milling Machine,**" by Mr. Samuel Dixon, M.I.Mech.E., Manchester.

Oct. 24.—On "**Water Power and its Development,**" by Mr. Geo. T. Pardoe, London.

Nov. 14.—On "**Ropes and Rope Driving,**" by Mr. G. H. Kenyon, Dukinfield.

„ 28.—**Reminiscences of the Visit of the Iron and Steel Institute to Spain,** by Mr. Henry Webb and other Members.

In conclusion, the Council beg to express their appreciation of the acceptable and valuable services rendered to the Association by members and others in reading papers and contributions to the discussions during the year.

Their thanks are also especially due to a member, Mr. F. W. Webb, and through him to the L. & N. W. Railway Company for allowing the Association to visit the noted Crewe Locomotive Works.

Similarly, they desire to record their obligations to another member, Mr. William Henry Hunter, of the Manchester Ship Canal Company, for the vigorous personal interest which he evinced in the visit of the members to the Company's Works at the Opening Meeting.

ANNIVERSARY DINNER.

The Fortieth Anniversary Dinner of the Association was held on Saturday evening, February 8th, at the Grand Hotel. Mr. Joseph Nasmith, the President of the Association, occupied the chair.

Mr. M. Ingram proposed "Our Municipal Corporations." Half a century had elapsed, he said, since our Municipal Government was established, during which period vast progress had been made in the welfare of the district and inhabitants generally. Previous to that, the sanitary environments of the people in this city and surrounding district were very unsatisfactory. A more perfect knowledge of advancing civilisation had made a continuation of these evils impossible. Much yet remained to be done ere we attained approximately to a state of ideal perfection. We owed a debt of gratitude to our Municipal representatives for the ability and self-sacrifice they had displayed in providing us and future generations with means by which we could enjoy more perfect health and lead more useful lives. (Hear, hear.) He regretted, however, to say that our public parks and open spaces were too few in number and far too circumscribed in their area. He commended the splendid enterprise shown by the Manchester Corporation in the direction of technical instruction. (Hear, hear.)

Alderman Hoy, who responded, said he hailed the opportunity to speak to men who understood something about the work done by the Corporation. Speaking from experience of Corporation affairs, he was prepared to say that there was a very large amount of sound and good work accomplished for the citizens.

There was nothing so expensive as the pursuit of good health, and nearly all of the increase in the rates was owing to the endeavour of the Corporation to improve the sanitary condition of the city. He wished that men like the members of the Association, who knew something about the work of the Corporation, would give them a bit of a lift at times when the merest clap-trap was made to do duty for criticism. He felt sure that this clap-trap was prompted by a craving for notoriety, and by that love of scandal which, he was afraid, was inherent in us all. He felt proud to belong to the Corporation, and he could prove to them, in spite of the adverse criticisms, that many things were done there that redounded greatly to the credit of those who carried the work out. (Applause.) The way in which the meetings were managed, the promptitude with which business was begun, and the straightforwardness and skill at all times carried out was commendable in a marked degree. The Thirlmere scheme, as a single example, illustrated the methods and attention devoted to the work by the Corporation. When the scheme was before Parliament they were continually told by their opponents that we should be saddled with a rate of a shilling or fifteenpence in the pound when it was completed. But what were the facts? The great works had been carried out at a cost of three million pounds in such a skilful way that not a penny had been added to the rates. (Applause.) This was the first year after the completion of the works, and also after certain other advantages had been given to the consumers. Alluding to the work of the Technical Instruction Committee, of which he was the chairman, Alderman Hoy said a scheme of mutual co-ordination of instruction between the Committee and the School Board had already been put into practice. He believed that before twelve months were over they would be able to show to the public that they had succeeded in a particular scheme of gradation of teaching throughout the whole of Man-

chester, which would be, at any rate if not perfect in itself, the best specimen that the country could afford. He urged upon all parents not to be too anxious to take their children away from school. Referring to the prosperity of the city, he pointed out that at the present time there were now more building operations in progress in Manchester than there had ever been before. (Applause.)

Councillor J. Saxon also responded to the toast.

Mr. E. Windsor Richards, President of the Institute of Mechanical Engineers, gave the toast of the evening, "Prosperity to the Manchester Association of Engineers." It had been the fashion for some time, he said, to decry our own industries. It was usual to say that our right hand had lost its cunning, that in technical education we were behind our Continental neighbours, who were taking the trade from us, and that England would soon be left high and dry amongst the nations of the earth. Some gentlemen who lately went out to Germany and Belgium, and had a run through some of the works there, had come to the conclusion that we were not so fit to manage our business as our friends on the Continent. Well, many of them would remember the visit paid by members of the Iron and Steel Institute to Belgium, where they were hospitably entertained and had an opportunity of inspecting the principal works. He felt bound to say that they found the works exceedingly well and carefully managed, but that they were better managed than English works he was not prepared for a single instant to admit. (Applause.) No doubt our friends on the Continent had taken away a great deal of our trade, but that was not because we were less skilful than they, but because of their large tariffs, which prevented us sending our manufactures into their countries, while they could send their manufactures into our country without paying any tariff whatever. Let the

foreigners withdraw their tariffs, and they would soon find that we were able to hold our own with them. (Hear, hear.) He congratulated the Manchester Association on its prosperity, and expressed a hope that it might continue to flourish.

The PRESIDENT, speaking in acknowledgment of the toast, said he felt it an honour to be the President of an Association which might be considered to represent the democracy of the profession, while the larger associations, with their headquarters in London, represented the aristocracy of the profession. He did not know, on the whole, that such associations as theirs did not do quite as useful a work as some of the larger associations of which some of them were proud to be members. He considered that they did an important work, if only by bringing into contact with each other for mutual benefit the men who were engaged in doing the drudgery work of the profession – the men who worked silently in the drawing office or in the noisier works, but on whose efforts to a large extent depended the excellence of those products which had given England its great name. (Hear, hear.) Such men, plodding along year in, year out, must at times feel discouraged by the lack of public recognition of their efforts. He ventured to put in a plea on their behalf. It was the daily duty done by such men, "the many mickles making the muckle," which in the long run, in the words of the Charter of the Institution of Civil Engineers, "utilised the works of nature for the convenience of man." From the point of view of what it did in the bringing of such men together and aiding those of them who by stress of circumstances had fallen into penury, the Association was doing much to advance the prosperity of the profession, and thereby to advance the prosperity of the country generally. (Applause.)

Mr. W. H. HUNTER proposed "Our Guests," for whom Mr. OSCAR HALL (Bury) and Mr. JAMES PLATT (Gloucester) replied.

The latter described an incident which had come within his own experience in illustration of the extent to which Germany is trying to keep its own trade to its own people. His firm had executed an order for machinery for a firm in Germany, and when more machinery of the same kind was required his firm was asked to name a price. They did so, but were told the price would not do. Thereupon, anxious to secure the order, they wrote stating a price which included practically nothing for carriage or duty. They got the reply that it was a very liberal concession, but that it did not meet the difficulty; the Germans did not care to encourage firms that had work done in England. And to show that this was not mere sentiment, the German firm mentioned that they recently lost a good customer because it was found that they were using machinery that had been made in England. And so, added Mr. Platt, the order was executed by a German firm, who very likely copied his firm's machinery.

Mr. T. Daniels gave "The Trade of the District."

Mr. Elijah Helm, Secretary of the Manchester Chamber of Commerce, who replied, referred to the murmurs sometimes heard from cotton spinners and manufacturers when they observed the large and rapidly growing exports of textile machinery from this country. He said he did not think that these murmurs were anything more than the expression of a momentary misgiving. Lancashire men were too far-seeing to think seriously of preventing or hindering the export of machinery, however they might deplore the artificial conditions under which it was worked in other countries. It was not always so. There were still in existence at the Chamber of Commerce the minutes of a vigorous society established in Manchester in 1799 which carried on prosecutions against offenders under the then existing laws, punishing by severe penalties of fine and imprisonment all who sent machinery out

of the country or engaged British artificers to transfer their services to foreign manufacturers. Happily it was now understood that one of the most important causes of the high efficiency and the success of home manufactures was the existence in this nation of an energetic, alert, and progressive engineering industry. This, however, could not maintain its supremacy if, by hindering the unrestrained outward flow of machinery, we should encourage and even help to perfect rival engineering establishments abroad. Free Trade in its widest sense, and the maintenance of the highest degree of personal efficiency on the part of all engaged in our manufactures of every kind, were the guarantees of their permanence, next to, perhaps quite as much as, our possession of an abundance of the primary instruments of production, coal and iron. (Applause.)

The last toast on the list was the health of the Chairman, proposed by Sir E. Leader Williams.

During the evening Mr. J. H. Greenwood's glee party sang a number of songs in creditable style.

LIBRARY.

The following new books have been purchased and added to the Library :—

Factories, Commercial Organisation of.	Lewis.
Gas and Oil Engine.	Clerk.
Gas Engine.	Norris.
Mechanical Engineering.	Lineham.
Power Locomotion.	Jenkins.

The Council have pleasure in acknowledging the following donations to the Library :—

Economisers, Fifty Years Development of, by W. H. Fowler.
Presented by Mr. J. Parker, Member.

Machine Drawing, by T. & T. J. Jones.
Presented by Mr. T. Jones, Member.

The Association exchanges Transactions with the following :—

American Institute of Mining Engineers.
" Society of Mechanical Engineers.
Canadian Society of Civil Engineers.
Engine, Boiler, and Employers Liability Insurance Company.
Franklin Institute, America.
Institution of Civil Engineers of England.
" Engineers and Shipbuilders in Scotland.
" Mechanical Engineers.
Iron and Steel Institute.
Liverpool Engineering Society.
Manchester Geological Society.
" Literary and Philosophical Society.
Midland Institute of Mining, Civil, and Mechanical Engineers.
Mining Association and Institute of Cornwall.
Mining Institute of Scotland.
National Boiler Insurance Co.
North of England Institute of Mining and Mechanical Engineers.
North-East Coast of Engineers and Shipbuilders.
South Wales Institute of Engineers.
Society of Engineers.

The following Publications are received periodically :—

Colliery Guardian.
Electrical Review.
Engineer.
Engineering.
Industries and Iron.
Iron and Steel Trades' Review.
Marine Engineer.
Mechanical World.
Practical Engineer.
Textile Mercury.
" Recorder.
" Manufacturer.

REPORT OF EXCURSIONS.

VISIT TO CREWE, THURSDAY, JUNE 25th, 1896.

On Thursday, June 25th, the Members paid a visit to the Crewe Locomotive Works of the L. & N. W. Railway Company, which had been kindly thrown open for their inspection by Mr. F. W. Webb, J.P., Chief Mechanical Engineer of the Company. The party were conducted through the extensive range of shops, commencing at the Bessemer steel works, and preceding *seriatim* through the various departments, following the work until it is turned out complete.

Fourteen years ago the Association paid a similar visit to the Crewe Works, and those Members who formed a portion of the party on the first occasion had an opportunity of inspecting the developments which had taken place during the above period, and the extensive introduction of modern tools and appliances. Since the first visit of the Society the steel rail mill has been completely remodelled, and laid out for rolling 60ft. rails. A signal manufacturing department has been added, new foundries have been erected, and other considerable extensions carried out until there is now a covered-in area of shops of nearly 50 acres, and at the present time 7,000 men are employed in the works.

Amongst the noticeable features was the introduction of electric tools and plant, the former including a number of very ingenious appliances designed by Mr. Webb, with independent motors, for sawing off both externally and internally the ends of boiler tubes, and for other purposes connected with locomotive building and repairs; the electric welding process was also seen in operation, and a large number of electrically driven cranes with independent motors for each separate motion have also been put up in the principal shops. Pneumatic riveters and a pneumatic caulking machine also attracted considerable attention.

Amongst other quite modern appliances were paint-spraying machines, and another feature was the very large adoption of powerful gas engines for driving separate shops. The works, which in some operations are kept running night and day, were chiefly engaged upon repairs, about four locomotives passing through every day, but there were also in hand twenty of the new three-cylinder compound heavy goods engines for drawing

exceptionally heavy loads and travelling over steep gradients, which were an object of interest to the Members.

On the completion of the tour of inspection, Mr. Webb, and Mr. Earle (the Assistant Manager), who had shown the members through the various shops, accompanied them to the special train, and expressed the pleasure it had given them to afford the Association another opportunity of seeing what was being done at the Crewe Works.

The Members afterwards sat down to tea at the Station Hotel, Mr. Joseph Nasmith, the President, occupying the chair. After referring to the fact that the Members of the Association had, 14 years ago, visited the Crewe Works, and that those who were present on the first visit would that day have had an opportunity of seeing the very material changes that had taken place during the meantime, he said that Crewe had long been the Mecca of the railway world, and although during recent years other large similar establishments had sprung into existence, there was no doubt that the successful organization of the Crewe Works stood to-day, on the whole, without a rival throughout the civilized world. The L. & N. W. Railway was an organization of which Englishmen might well be proud, and the position of pre-eminence in which it stood was largely due to the Engineer who so ably guided and controlled the works through which they had gone that afternoon, and for their great indebtedness to Mr. Webb, who had so courteously thrown open the works for their inspection, he begged to propose that the best thanks of the Association should be given.

Mr. Daniels briefly seconded the motion, which was supported by Mr. Ashbury, who referred to the extraordinary development of Crewe since the establishment of the L. & N. W. Works.

OBITUARY.

THOMAS STUBBS CANNELL served his apprenticeship as a Pattern-maker, with Mr. Richard Kitchen, of Warrington, and for upwards of 22 years held an important managerial appointment with the firm of Messrs. J. Shaw & Sons, Salford.

He was elected an Ordinary Member, March, 1885. He died suddenly, August 27th, 1896, aged 55 years.

JOHN GALLOWAY was born July 18th, 1826, in Great Jackson Street, Manchester.

The name of Galloway is closely connected with one phase of the rise and progress of Manchester from the latter end of the last century. As far back as 1790 there came to this city a Mr. William Galloway, a native of Coldstream, on the north side of the Tweed, who commenced business in Great Bridgewater Street as a millwright, his workshop being situated at the corner of Albion Street, Gaythorn. Later on Mr. James Bowman, a Coldstream fellow-workman of his, entered into partnership with him, and in 1820 the introduction of another partner caused the name of the firm to be altered to "Galloway, Bowman, and Glasgow." Coming down to 1835, we find further change. In that year Mr. William Galloway (the father of the subject of this sketch) and his brother, the late Mr. John Galloway, established the Knott Mill Ironworks, under the title of "W. & J. Galloway," a foundry and a small shop for doing simple engineering work being first erected. The introduction into the firm of the deceased gentleman, Mr. Charles J. Galloway (son of his brother), and (subsequently) of Mr. E. N. Galloway, another son, led to the addition "and Sons" in 1856; while in 1889 "Galloways Limited" was constituted, with Mr. C. J. Galloway as Chairman, and the deceased as Vice-Chairman. This, in brief, is a history of "Galloways." It is interesting to note how the business, originally confined to millwrighting, afterwards embraced locomotive work (the firm constructed the first railway engine built in Manchester), and finally developed into the boiler making which has made the name of "Galloway" known far and wide. In 1872 the great increase in the business necessitated the construction of the Ardwick Works, where fully one large boiler per day is now turned out. The improvements which the firm have made in this form of steam generator are matters of common engineering knowledge. Early in life the

subject of this notice was initiated into the practical work of the business, for, after receiving his education at Southport, he was apprenticed to "W. & J. Galloway" at the age of 14.

Mr. Galloway was one of the best known of Manchester's sons. Whether in business relations, in philanthropic labours, or in political work, he was everywhere esteemed for his characteristic energy, thoughtfulness, and large-hearted generosity, In addition to his duties as Vice-Chairman of "Galloways Limited," he was for many years Chairman of Earle's Shipbuilding and Engineering Company, Hull; and served on the Boards of Directors of the Carnforth Hematite Iron Company, the North of England Trustee, Debenture, and Assets Corporation Limited, and the Hoyland and Silkstone Colliery Company. Moreover, he was for 30 years a Director of the Blackpool Land Company, and in connection with his tenure of office there it is worth noting that the Shareholders, at their annual meeting held recently, voted a sum of money with which to purchase some silver plate for presentation to Mr. Galloway and Mr. May (the Chairman of the Company) in recognition of their valuable services. His abilities in financial matters were particularly marked, this department of the firm being his special charge. In 1887 he was induced, after very great pressure, to accept the Chairmanship of the Committee which managed the finances of the Jubilee Exhibition in Manchester, and in that capacity rendered services which were publicly acknowledged. For 30 years or more he was a Magistrate for the city and for the county.

As a philanthropist and friend of the poor and suffering he made for himself a name which will not be soon forgotten. His charity was not ostentatious. Giving freely and willingly, he sought no public reward, but the people of South-West Manchester were not inappreciative.

Mr. Galloway was elected a life honorary member in the year 1872. He died December 16th, and was interred at the Salford Cemetery.

William Henry Peacock served his apprenticeship with his father, Ralph Peacock, who was a marine engineer and shipbuilder at Goole. Subsequently, for about 12 years, he was a draughtsman, and afterwards a foreman, with the firm of Messrs. Beyer, Peacock & Co., Manchester. About ten years ago he became proprietor of the Townley Iron Works, Bradford.

He was elected an Honorary Member in 1888, and died very suddenly September 3rd, 1896, aged 41 years.

TREASURER'S GENERAL CASH ACCOUNT, for year ending 31st December, 1896.

Dr. (Including Superannuation Fund Account:) **Cr.**

1896.		£	s.	d.
Jan. 1.	To Balance as per last Report	3,645	15	1
Dec. 31.	„ Contributions and Entrance Fees	523	10	0
	„ Transactions—sold	4	5	0
	„ Interest from Mortgages on Properties £94 6 2			
	„ „ „ Leeds Corporation 3½ % Stock 20 6 0			
	„ „ „ Bank 4 5 5			
		118	17	7
		£4,292	7	8

Audited and found correct,

GEORGE KIERNAN,
J. BARTLAM,
J. E. KELSALL, } AUDITORS.

Sept., 1896.
5th Jan., 1897.

1896.		£	s.	d.
Jan. 1.	By Rent—Grand Hotel	20	0	0
to	„ Secretary's Salary £45 0 0			
Dec. 31.	„ Librarian's „ 10 0 0			
		55	0	0
	„ Superannuation Allowance	91	19	6
	„ Printing and Lithography of Transactions £128 17 3			
	„ Binding of do. 20 9 6			
	„ General Circulars and Miscellaneous Work 18 6 3			
	„ Stationery 0 15 6			
	„ Members' List (1897) 16 11 6			
		180	0	0
	„ Insurance premium on Library	0	6	0
	„ Expenses re Anniversary Dinner	14	18	3
	„ Audit, General Council & Sub-Committee Exs. £12 10 9			
	„ Postages of Circulars, Papers and Correspondence 34 5 2			
	„ Sundries and Expenses re Papers 11 19 7			
		58	15	6
	„ Delivery of Annual Volumes	6	0	2
	„ Funeral Allowance:—Mr. T. Cannell	10	0	0
	„ Expenses re Paper "Water Power"	3	0	0
	„ President's Expenses re Mechanical Engineers' Dinner	2	10	0
	„ Cash invested in Building Society £75 0 0			
	„ „ „ Properties: Mortgages 3,050 0 0			
	„ „ „ Leeds Corporation 3½ % Stock... 600 0 0			
	„ „ „ Premium on do. 90 6 6			
		3,815	6	6
	„ Cash in Bank £7 8 5			
	„ „ Treasurer's hands 16 14 7			
	„ „ Secretary's „ 10 8 9			
		34	11	9
		£4,292	7	8